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**PHASE II RCRA  
FACILITY INVESTIGATION REPORT**

**VOLUME 1 OF 2**

**PREPARED FOR  
AlliedSignal FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

**EPA PERMIT NUMBER PAD002312791**

**BROWN & ROOT ENVIRONMENTAL PROJECT NUMBER 0091**

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## **1.0 INTRODUCTION**

Brown and Root (B&R) Environmental (formerly known as Halliburton NUS Corporation) conducted the Phase II Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for the AlliedSignal Frankford Plant (the Plant), in Philadelphia, Pennsylvania. This report summarizes pre-Phase II RFI investigative activities and presents the results of the Phase II RFI field work conducted from June 1993 through December 1993.

### **1.1 SITE LOCATION**

The Plant is located in northeastern Philadelphia at approximately 40°00'24" north latitude and 75°04'07" west longitude (see Figure 1-1). The Plant property is bounded on the west by Margaret Street, on the north by Interstate 95, on the east by Bridge Street, and on the south by the Frankford Inlet, the Frankford Inlet sewer right-of-way, and Almond, Pratt, Belgrade, Ash, and Gaul Streets (see Figure 1-2). The Frankford Inlet discharges to the Delaware River approximately 1/2 mile east of the facility. Both the Frankford Inlet and the Delaware River are tidal in the reaches near the facility.

The Plant lies in the Bridesburg section of Philadelphia, Pennsylvania. Immediately adjoining the facility to the south is a densely populated residential area. A mixed residential/industrial area lies across Interstate 95 to the north of the facility. The TIP Trailer sales lot (F.P Woll property) is located immediately west of the Plant. The Arsenal Business Center and Rohm and Haas Delaware Valley, Incorporated Philadelphia chemical plant are located east of the Plant.

The Plant property is generally flat and is situated five to 15 feet above mean sea level. The property gradually slopes to the south, toward the former Frankford Creek creekbed, which was rerouted circa 1952 (Kearney, 1987).

### **1.2 REGULATORY BACKGROUND**

In September 1990, the United States Environmental Protection Agency (EPA) issued the RCRA Permit for Corrective Action for the Plant. One requirement of the permit was to conduct an RFI for 12 Solid Waste Management Units (SWMUs) and two areas of concern (AOCs) at the Plant.

The first task of the RFI was to develop the RFI work plan. During development of this plan, AlliedSignal and EPA agreed to a phased approach to investigate the facility because of the dearth of existing data on shallow groundwater flow at the Plant. The first phase of the RFI concentrated on delineating the extent of a previously detected light non-aqueous phase liquid (LNAPL) layer and soil contamination at the Plant. Three groundwater monitoring wells were installed during the Phase I RFI. The final Phase I RFI Plan was submitted to EPA in May 1991 (NUS, 1991). This plan was approved by EPA in the following month.

Phase I RFI field work was conducted from December 1991 through February 1992. The draft Phase I RFI report was issued to EPA in May 1992. Two of the conclusions of the Phase I RFI were that a layer of LNAPL underlies the central portion of the Plant and that soil contamination exists at the Plant (Halliburton NUS, May 1992).

Based on the Phase I RFI results, AlliedSignal voluntarily conducted a conceptual design study to evaluate potential LNAPL recovery enhancement alternatives. (An LNAPL recovery system has operated at the Plant since 1984.) The results of the study, which were published in February 1993, concluded that active LNAPL-only recovery systems (e.g., LNAPL-only pumps) and passive LNAPL recovery systems (i.e., product recovery filters with collection canisters) presented the two best alternatives for system enhancement. Previous work had indicated that chemical incompatibility between LNAPL constituents and commonly used recovery system construction materials (e.g., PVC and aluminum) existed. Based on the potential chemical incompatibility of vendor systems, pilot testing was recommended by AlliedSignal prior to the final system design (Halliburton NUS, 1993).

On November 9, 1992, EPA asked AlliedSignal to conduct an Interim Measure to enhance the LNAPL recovery system at the Plant (EPA, November 1992).

Between March 1993 and June 1993, AlliedSignal performed pilot testing on the four vendor systems (two active and two passive) believed to be most suitable to the site. Based on the pilot testing results, it was recommended that a network of active pumping wells be installed to enhance the LNAPL recovery system (B&R Environmental, July 1993). On August 20, 1993, AlliedSignal formally requested EPA to modify its corrective action permit to incorporate enhancement of the LNAPL recovery system using active pumping as an Interim Measure (AlliedSignal, August 1993). A 30-day public comment period was held to solicit public input on this request. After the close of the comment period, EPA granted the Class II Permit modification on October 29, 1993 (EPA, October 1993). Detailed design of the recovery system is currently ongoing.

In the same November 9, 1992 letter cited previously, EPA approved the draft RFI report as the final Phase I deliverable. As a part of its approval, EPA requested that a Phase II RFI be conducted, with the primary objective being the delineation of the extent of shallow and deep groundwater contamination. Since the Phase I RFI work plan had been previously approved by EPA, EPA did not require submission of a Phase II RFI work plan for approval, as long as the same field sampling protocols were followed. EPA also agreed with AlliedSignal that the Plant should be treated as one large study areas similar to a Corrective Action Management Unit for the Phase II RFI and future investigative/remediation efforts (EPA, November 1992).

On December 8, 1992, AlliedSignal responded to the EPA November 9, 1992 letter by requesting a reduction in the chemical analytical suite for the field investigation (AlliedSignal, December 1992). On January 21, 1993, EPA approved this request (EPA, January 1993). At this point, B&R Environmental was engaged by AlliedSignal to design and implement the Phase II RFI.

This report presents the results of the Phase II field effort. The data generated during this effort, along with data collected previously at the site, are used to support the study conclusions and to support the scoping of additional site studies.

### **1.3 PHASE II RFI OBJECTIVES**

The objectives of the Phase II RFI as outlined in EPA's November 9, 1992 letter are as follows:

- Determine the extent of groundwater contamination in both the shallow aquifer and the deep sand unit, including determination of whether off-site migration has occurred.
- Determine the continuity and permeability of the silt-clay layer under the site.
- Determine tidal effects on groundwater elevation, flow direction, and migration of contamination.
- Determine the primary factor(s) controlling groundwater flow.
- Determine use of any shallow aquifers within a one-mile radius of the site.
- Verify if free product (LNAPL) or groundwater is seeping into sanitary, city, or storm sewers running through the Plant.

- Determine if there is a possibility of backflow of contaminated groundwater into drinking water lines.
- Determine discharge points of lines containing contaminated groundwater.

Several tasks were used to accomplish these objectives. These tasks included: installation of a piezometer network; direct shallow groundwater sampling with analysis in a onsite mobile laboratory installation, sampling for chemical analysis, and slug testing deeper and shallow monitoring wells; advancing soil borings to further define the Plant subsurface geology; and performing long-term water-level recording in potentially tide-affected monitoring wells. In addition, existing drinking water line and sewer line chemical data were evaluated, all Phase II RFI data were validated, a potable water supply well survey was conducted, and a risk assessment was performed.

#### **1.4 FACILITY HISTORY**

The following facility history, up to 1959, is excerpted primarily from "History of Frankford Plant (draft)," authored by T. Lee (1959). The post-1959 Plant history was compiled from various sources, which are referenced where applicable.

Operations at the Plant commenced in 1884 on a 4.5-acre lot. The first owner, the H.W. Jayne Company, in conjunction with M. Ehret, Jr. and Company, initially employed 30 workers. The 1884 operations consisted of converting coal tar lights oils and crude naphthalene to tar acid, solvent, and naphthalene products. Moth balls were made by hand.

In 1896, the Jayne Company was absorbed into the Barrett Manufacturing Company. By 1899, the Plant area had increased to seven acres, and approximately 60 workers were employed. Production was on a relatively small scale: three months were required to produce 10 gallons of purified phenol, and two months were needed to produce the equivalent of a tank car full of benzene.

Between 1896 and 1916, new processes and products were introduced at the Plant. In 1916, the Plant area exceeded 17 acres, and 300 workers were employed. Operations in 1916 were bordered by Frankford Creek to the south, Margaret and Buckius Streets to the west, Bermuda and Stiles Streets to the north, and Wakeling Street to the east (Barrett, 1916). Products included benzene, toluene, naphthalene, anthracene, cresols (methylphenols), resorcinol, cresylic acid, nitrobenzene, nitrotoluene, nitronaphthalene, aniline, toluidine, naphthylamine, pyridine, carbazole, disinfectant oils, and semi-refined solvents and oils. Noted impurities included thiophene, carbon disulfide, acridine, and chrysogene (Barrett, 1916).

During World War I, the Plant's product line was expanded to include the production of basic coal chemicals and derivatives required for the production of trinitrotoluene (TNT), picric acid, dyestuffs, and pharmaceuticals. Previously, many of these products could be obtained only from Germany. By 1918, the Plant had expanded to include 76 buildings, with 1,000 employees. The first phenol production unit at the Plant was constructed in 1918.

In 1920, the Barrett Manufacturing Company was incorporated into the Allied Chemical Corporation. Also at this time, Plant operations were limited to the separation and purification of coal chemicals found in carbolic oils and light oils. The Plant's remaining products included refined benzene, toluene, and xylene; various semi-refined solvents; tar acids (phenol, cresols, and cresylic acids); pyridine, alpha-picoline, beta- and gamma-picoline, lutidine, and collidine; crude and refined naphthalenes (including methylnaphthalene); and cumarene-indene resins. Processing of light oils and carbolic oils continued at the Plant until 1960 and 1972, respectively (Allied Chemical, 1978).

During the late 1930s production of coal chemical derivatives and synthetics resumed at the Plant. From 1935 to 1945, 4-chloro-m-cresol was reportedly produced. Additionally, 1,3,5-xyleneol production commenced at this time. This production was discontinued in 1971 (Allied Chemical, 1978).

In 1937, the first phthalic anhydride unit was constructed at the Plant. Phthalic anhydride was produced from refined naphthalene. A second phthalic anhydride unit was installed at the Plant in 1942, and a third unit was constructed in 1955. By 1969, approximately 100 million pounds of phthalic anhydride were produced annually. Small amounts of by-products, chiefly naphthoquinone and maleic anhydride, were created during the production of phthalic anhydride. During 1972, a fire in the phthalic anhydride production unit led to the cessation of phthalic anhydride manufacturing operations at the Plant (Allied Chemical, 1976).

In 1940, a second phenol unit using the sulfonation fusion process was placed into operation. This unit operated until 1953, when the Plant converted to the cumene-phenol process.

In 1942, the Plant began converting some of its phthalic anhydride product into phthalate esters, using purchased alcohols (e.g., butanol and hexanol). The principal product during World War II was dibutyl phthalate. After 1945, dioctyl phthalates (2-ethylhexyl, isooctyl, and capryl) became the most important products. Adipate plasticizers were also produced prior to 1969, using solid adipic acid in place of phthalic anhydride. In 1971-1972, production of plasticizers at the Plant was terminated (Allied Chemical, 1976).

In 1944, nicotinic acid (niacin) production from quinoline (a heavy tar base derivative) commenced. Production of quinoline was initiated simultaneously. Quinaldine and isoquinoline were also reportedly produced. In 1962, the nicotinic acid production was discontinued (AlliedChemical, 1976).

About 1952, Frankford Creek was straightened, and the meander and former creekbed on the Plant property was backfilled. The fill material may have included ash from the City of Philadelphia's incinerator plants.

Production of phenol and acetone by the cumene process was initiated at the Plant in early 1954. At this time, cumene was produced at the Plant by reacting propylene with benzene. By-products of the phenol process included alpha-methylstyrene (AMS) and acetophenone. In 1954, an explosion damaged Phenol Production Unit No. 1, which was rebuilt. In 1960, a second synthetic cumene/phenol unit was placed into production. A third unit was added in 1964. In 1982, an explosion and fire damaged part of the phenol production facilities (Phenol Unit No. 1). These facilities were partially rebuilt in 1983. The cumene/phenol process is the only remaining production currently occurring at the Plant (AlliedSignal, 1987)

In 1955, a major fire damaged the cumene production unit at the Frankford Plant. This unit was rebuilt shortly thereafter. Cumene production at the Plant ceased around 1960, when it became cheaper to buy cumene from local refineries than to make it at the Plant.

Prior to 1955, all Frankford wastewaters were treated and discharged to Frankford Creek. Beginning in 1955, the Plant began discharging the majority of its wastewaters to the Philadelphia Northeast Water Pollution Control Plant. Wastewaters are biologically treated at this plant.

During strikes in 1960 and 1966, approximately 700 tons of phthalic anhydride mother liquor were reportedly temporarily landfilled at the Plant at two locations (adjacent to Bridge Street and near the former spray ponds). This material was reportedly excavated and disposed off site after the strikes were settled.

In 1973, Allied began the demolition of outmoded facilities (i.e., the non-phenol-production facilities). This program continued through 1978.

Late in 1981, Allied discovered a layer of LNAPL floating on top of the water table beneath Phenol Process Unit No. 2. Groundwater withdrawal to contain this layer commenced in June 1984. This withdrawal system is currently operating.



In December 1982, approximately 11,000 gallons of 50 percent caustic escaped from a ruptured tank. A groundwater withdrawal system to recover the caustic was installed in May-June 1983. This withdrawal is currently continuing.

An Allied employee also reported that unknown quantities (believed to be less than 20 cubic yards) of naphthalene, tar acid, and tar base sludges generated from tank demolition activities were also disposed on site.

The history of permits issued to AlliedSignal can be found in the Phase I RFI Plan, Volume 1 (NUS, 1991). Currently, the Plant has a National Pollutant Discharge Elimination System (NPDES) permit to discharge water softener backwash, non-contact cooling water, and storm runoff to Frankford Inlet. The Plant also has a permit from the City of Philadelphia to discharge process wastewater, recovered groundwater, sanitary wastewater, and some stormwater to the Philadelphia Northeast Water Pollution Control Plant. The Plant also has approximately 50 air pollution operating licenses (to construct) and permits (to operate) from the City of Philadelphia.

## **1.5 REPORT ORGANIZATION**

The Phase II report is organized as follows:

Section 2.0 includes a discussion of field procedures and analytical procedures used during the Phase II RFI.

Section 3.0 contains a discussion of the Plant's environmental setting, including information about climate, geology, surface water, hydrogeology, and local water and land uses.

Section 4.0 presents a summary of previous investigation activities and the results of the Phase II sampling and analysis program.

Section 5.0 contains a discussion of fate and transport properties for chemicals detected at the Plant.

Section 6.0 presents the health and environmental assessment for the RFI. This section also includes a discussion of potentially applicable regulatory criteria and guidelines.

Section 7.0 presents the conclusions and recommendations of the Phase II RFI.

### **3.0 ENVIRONMENTAL SETTING**

#### **3.1 CLIMATE**

The Plant lies within the Pennsylvania Coastal Plain. The climate of the Pennsylvania Coastal Plain is classified as humid continental. The Appalachian Mountains to the west and the Atlantic Ocean to the east have a moderating effect on the climate of this area.

Summers in this region are long and, at times, uncomfortably hot, and winters are comparatively mild. Average monthly temperatures vary from about 31°F in winter to 76°F in summer. Daily temperatures reach 90°F or more an average of 25 days during summer and fall to the freezing point or below on fewer than 100 days during winter. Below-zero- and above-100-degree readings are relatively rare, and periods of very high or very low temperatures seldom last for more than three or four days [National Oceanographic and Atmospheric Administration (NOAA), 1982; NOAA, 1983].

Precipitation is fairly evenly distributed throughout the year, with an average annual precipitation of about 41 inches. Maximum rainfall amounts occur during the late summer months and are often associated with local thunderstorms. Humidity is relatively high, averaging about 57 percent annually, because of the area's proximity to the ocean (NOAA, 1982; NOAA, 1983).

The prevailing wind direction during the summer months is from the southwest, and during the winter, it is from the northwest. The annual prevailing wind direction is from the west-southwest, with an average speed of 9.6 miles per hour (NOAA, 1982; NOAA, 1983).

#### **3.2 TOPOGRAPHY**

The Plant property and nearby surrounding areas are generally flat to very gently sloping, with short, steeply sloping to vertical banks immediately adjacent to the Frankford Inlet. The principal exceptions to this generalization are the moderately to steeply sloping embankments adjacent to Interstate 95 and the highway's on- and off-ramps, located north and west of the Plant. The land surface north of the former Frankford Creek and the existing Frankford Inlet generally slope from north to south toward the former creekbed and existing inlet. The land surface south of the former creek and existing inlet generally slopes from south to north.

Land surface elevations at the Plant and nearby surrounding areas range from near sea level at the Frankford Inlet to about 20 feet above mean sea level along the northern boundary of the Plant adjacent to Interstate 95. The 100-year floodplain at the facility is 10.166 feet above mean sea level. Most of the Plant property south of Main Street and adjacent to the Frankford Inlet and the former Frankford Creek channel lies within the floodplain (Kearny, 1987).

### **3.3 SURFACE WATER HYDROLOGY**

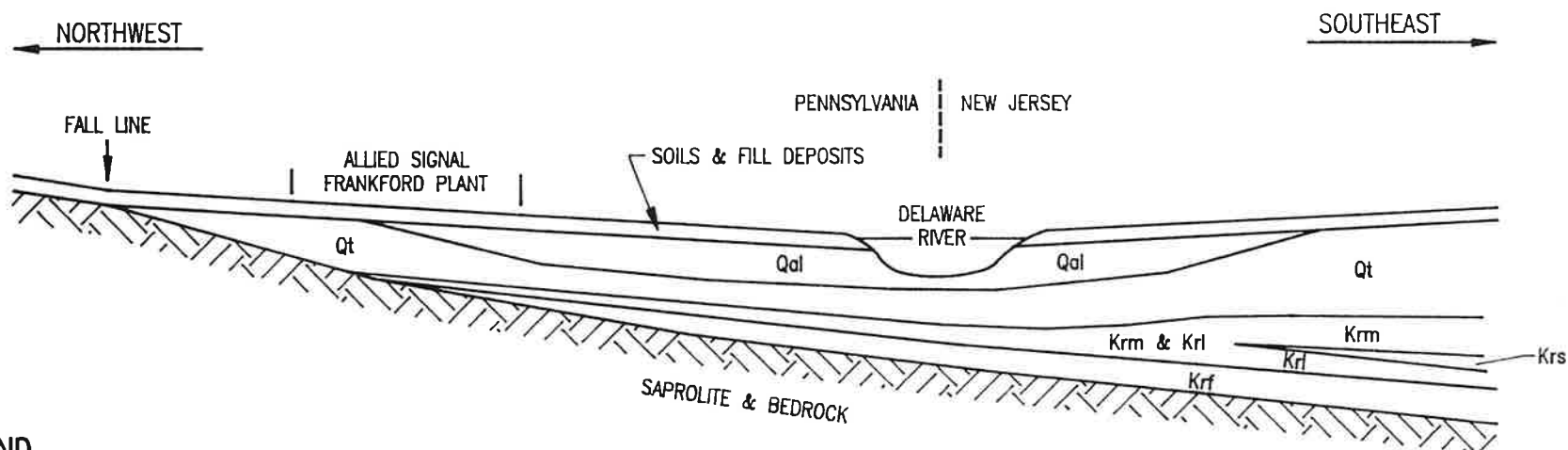
Estimates of surface runoff from precipitation at the Plant were made from the mapped and observed surface topographic features and from the Plant sewer lines plot plan. Surface water runoff within the Plant is generally from north to south, from higher elevations adjacent to I-95 toward lower elevations adjacent to the Frankford Inlet and the former creekbed. Significant surface water run-on has been observed entering the Plant along Wakeling Street at the northern Plant boundary. The Plant has made significant efforts to minimize the co-mingling of stormwater run-on and process area storm water.

Surface water runoff throughout most of the Plant from areas west of Wakeling Street and/or north of Main Street appears to be collected by sumps or drains entering either City of Philadelphia combined sewer lines or the Plant wastewater sewer system. Discharge of effluent from the Plant wastewater sewer system is to the city sewers. Surface water runoff in the southeastern part of the Plant, east of Wakeling Street and south of Main Street, is generally to the Frankford Inlet either by overland flow or through storm sewers that are permitted to discharge to the inlet.

The City of Philadelphia Frankford Inlet and Wakeling Street combined sewer lines may discharge to the Frankford Inlet during heavy precipitation events, via flood gates that are controlled by the City of Philadelphia Water Department.

Local surface water bodies in the vicinity of the Plant include the Frankford Inlet adjacent to the southeastern boundary of the Plant and the Delaware River located approximately 1/2 mile east of the Plant. The Frankford Inlet is an estuary of the Delaware River. The Delaware River flows to the southwest, toward the Delaware Bay.

The Frankford Inlet originates on the southeastern perimeter of the site. The inlet was formed when Frankford Creek was channelized west of the site and the former creekbed was backfilled. The Frankford Inlet receives NPDES-permitted wastewater and storm water discharges from the Plant, combined sewer system overflow from City of Philadelphia sewers, and discharges from the nearby Rohm and Haas Delaware Valley plant.



3-3

**LEGEND**

- Qal — Recent alluvial deposits
- Qt — Trenton Gravel (Pleistocene sediments)
- Krm — Raritan Formation, middle clay member
- Krs — Raritan Formation, Sayreville sand member
- Krl — Raritan Formation, lower clay member
- Krf — Raritan Formation, Farrington sand member

REFERENCE: Greenman, et al., 1961

NOT TO SCALE

**FIGURE 3-1**

**GENERALIZED GEOLIGICAL CROSS-SECTION**  
**AlliedSignal FRANKFORD PLANT, PHILADELPHIA PA**

**Brown & Root Environmental**

Both the Delaware River and Frankford Inlet are tidally influenced in the vicinity of the site. The mean annual tidal range in the Delaware River at Torresdale (approximately 5-1/2 miles upstream of the site) is 6.12 feet. Tides are semidiurnal.

### **3.4 GEOLOGY AND SOILS**

Descriptions of regional geology in the vicinity of the Plant are primarily excerpted from "Compilation of Available Site Hydrogeologic Data, Allied Chemical Corporation Frankford Plant" (Weston, 1980) and from "Groundwater Resources of the Coastal Plain Area of Southeastern Pennsylvania" (Greenman, et al., 1961). Descriptions of site-specific geology use information from the same references (Weston, 1980, and Greenman, et al., 1961) in conjunction with over 100 foundation test borings drilled on site by various contractors between 1937 and 1990 and new information obtained from the RFI Phase I and II soil boring and monitoring well installation programs.

#### **3.4.1 Regional Geology and Soils**

The Plant is located at the western edge of the Atlantic Coastal Plain Physiographic Province. The Atlantic Coastal Plain is an eastward-thickening wedge of predominantly unconsolidated sediments (i.e., gravel, sand, silt, and clay) extending from southeastern Pennsylvania across New Jersey. The western boundary of this clastic wedge is the Fall Line, which runs roughly in a northeast-to-southwest direction just west of the site. The approximate location of the Plant with respect to the various Coastal Plain sedimentary formations of the area is shown in Figure 3-1, a generalized geological cross-section of the Plant and nearby surrounding areas. This cross-section is based upon interpretations of regional geology presented in Greenman, et. al., (1961), but is not intended to be an exact representation of the regional or site-specific geological conditions.

Underlying the unconsolidated sediments is crystalline basement rock of the PreCretaceous Glenarm Series. These metamorphic rocks are of probable Lower Paleozoic age and may be of either sedimentary or igneous origin. They are fine- to coarse-grained, crystalline, dense, hard, and foliated or banded rocks characterized by an excess of mica. The lithologies present include hornblende gneiss, granite gneiss, and a sequence of alternating micaceous schist and quartzite. The upper surface has been weathered to a soft, gray, extremely micaceous clay (saprolite) that ranges from a few feet to several tens of feet in thickness and becomes firmer and more granular with increasing depth. The crystalline bedrock crops out northwest of the Fall Line and underlies the Coastal Plain sediments at generally increasing depths to the southeast. The southeastward-dipping surface of the bedrock has been channeled by the ancestral Schuylkill and Delaware Rivers and their major tributaries, including Frankford Creek, creating local variations in the elevation of the bedrock surface.

The basement bedrock complex is unconformably overlain in places by the Raritan Formation of Cretaceous age. In Pennsylvania, the Raritan Formation is represented by a sequence of nonmarine deposits representing three cycles of deposition. Each cycle contains a basal layer of coarse-grained (sand and gravel) deposits that are covered by layers of silts and clays. These cycles consist, in ascending order, of the Farrington sand, lower clay, Sayreville sand, middle clay, Old Bridge sand, and upper clay members.

Based on interpretations presented in Greenman, et al. (1961), the Old Bridge sand, Sayreville sand, and upper clay members of the Raritan Formation are not present in the area of the Plant. In the absence of the Sayreville sand, the lower and middle clay members are merged into a single unit that is interpreted by Greenman et al. to be present in the subsurface throughout the area of the Plant. The Farrington sand member is interpreted by Greenman et al. to be present only beneath the southeasternmost portion of the Plant, thickening toward the southeast.

The Farrington sand member consists primarily of coarse sand and fine gravel that grade upward into medium- to fine-grained sand with a few beds of white clay. It varies in color from yellowish gray to pale yellowish brown. The sands and gravels are fairly well sorted. The thickness of the Farrington sand is generally less than 60 feet in Pennsylvania, and it thins rapidly toward the margins of its occurrence.

The lower clay member consists mainly of tough brick-red clay containing beds of soft gray, well-stratified clay, and thin lenses of fine-grained sand. The texture and composition of the lower clay are fairly uniform; however, the sequence and thickness of the beds may vary considerably. The thickness of the lower clay is mainly between 20 and 40 feet, except near the margins of its occurrence.

The middle clay member has a much less variable lithology than the lower clay member and consists mainly of tough red and white clay, with a uniformly massive texture. It may contain a few thin beds or lenses of fine-grained sand and locally may contain a conspicuous bed of lignite at the base. The thickness of the middle clay is similar to that of the lower clay; however, in the Philadelphia area, these two clay members are in direct contact and cannot be differentiated.

Both the Raritan Formation and the bedrock are unconformably overlain by Pleistocene age (Quaternary System) sediments within the Delaware River valley. These sediments, formerly referred to as the Cape May Formation, are now known as the Trenton gravel. They consist of gray to brown and pale reddish-brown, very gravelly sand composed of medium- to coarse-grained, angular to rounded quartz sand grains, and pebbles, cobbles, and boulders of sandstone, siltstone, chert, quartzite, and mica schist. The Trenton Gravel is generally 30 to 40 feet thick and occurs at elevations of less than 20 or 30 feet above sea level. Much of the Trenton Gravel has been removed by erosion along the Delaware and Schuylkill Rivers.

Recent (post-Pleistocene) alluvial deposits overlie the older rocks and sediments beneath the channels and tidal flats of the Delaware River and its principal tributaries. They are fine-grained, richly organic sediments consisting of dark gray mud, silt, and fine sand. In most locations, the recent alluvial deposits are usually less than 10 feet thick and rarely more than 28 feet thick.

Soils in the area of the Plant are of the Urban land - Howell Association. The Plant locale is in an area of nearly level to gently sloping soils formed in loamy and clayey material of mixed, old Coastal Plain sediment. Urban land consists of areas that are built up and occupied by urban structures. Howell and other soils have been obscured, smoothed, disturbed, filled in, or destroyed by the construction of urban facilities. Howell soils are deep and well drained, have a moderately low permeability, and consist of silt loam and silty, sandy, or gravelly clay loam [United States Department of Agriculture (USDA), 1985].

#### **3.4.2 Site Geology**

Two deep soil borings, 34 shallow soil borings (including the Geoprobe borings), six deep monitoring well borings, and 20 shallow monitoring well borings were drilled at the Plant during the RFI Phase II field work. Four deep soil borings, 56 shallow soil borings, and three shallow monitoring well borings were drilled at the Plant during the RFI Phase I field work. Ten shallow observation and/or recovery wells were installed during the conceptual design investigation for free-phase product recovery. All of the monitoring wells and the Phase II shallow and deep soil borings are shown on Figures 2-1 and 2-5. The Phase I and II deep soil borings and the Phase II deep monitoring well borings are shown on Figure 3-2. The Phase I shallow soil borings are shown in Figure 2-1 of the Phase I RFI Report (Halliburton NUS, May 1992). Logs containing lithologic descriptions and other information for all of the Phase II soil and monitoring well borings are contained in Appendix B of this report. Logs for all of the Phase I soil and monitoring well borings are contained in Appendix B of the Phase I RFI Report (Halliburton NUS, May 1992). Logs for the 10 conceptual design investigation well borings are contained in Appendix B of the "Final Report for the Conceptual Design Study for Free-Phase Product Recovery" (Halliburton NUS, February 1993).

In addition to the RFI Phase I and II borings, AlliedSignal has undertaken numerous geotechnical investigations at the Plant to determine the suitability of the soils and subsurface materials for the foundations of buildings and other structures. B&R Environmental has identified 137 test borings that were drilled over the past several decades as part of these investigations. Boring logs completed between 1937 and 1990 have been located for 111 of these borings, 92 of which extended to bedrock. The locations of these deep test borings are shown on Figure 3-2, and the logs are included in Appendix C.

In 1983, Woodward-Clyde conducted a boring program to assess the caustic spill area. The following strata were encountered in descending order: approximately 12 to 23 feet of miscellaneous silty fill materials overlying 12 to 20 feet of gray organic silt, which overlies about five to eight feet of sand and gravel overlying schist bedrock (Woodward-Clyde, 1983). However, no drilling logs from these borings are available.

Lithologic descriptions of samples from the RFI Phase I and II borings have been used in combination with the deep foundation test borings and the available background information to create an updated geological model of the Plant. Unless otherwise stated, the elevations listed on test borings were assumed to refer to the Plant datum and were converted to the United States Geological Survey (U.S.G.S.) Mean Sea Level (MSL) datum prior to interpretation. For those borings where no elevations were given, the present ground surface elevation of that boring location was estimated using available information. It is possible that some of the estimated test boring elevations may be in error by as much as a few feet considering that different survey data may have been used for various areas of the Plant in the past and that the ground surface elevations in certain areas may have changed with the addition or removal of fill materials.

The geological model consists, in descending order, of three basic units: surficial fill deposits, unconsolidated sedimentary deposits, and the underlying saprolite and bedrock. The unconsolidated sedimentary deposits are further subdivided into a sand and gravel unit, a recent silt-clay unit, and an older silt-clay unit.

The general configuration of the geologic interpretation and individual geologic units is illustrated by cross-sections (see Figure 3-3 for the locations of the cross-sections). Cross-sections A-A' through G-G' (Figures 3-4, 3-5, and 3-6) extend from northwest to northeast or from north to south, roughly perpendicular to the geological contacts of the site. Cross-sections H-H' and I-I' (Figures 3-7 and 3-8) extend from west to east and are parallel to the geological contacts (strike) of the units at the site.

#### **3.4.2.1 Surficial Fill Deposits**

Lithologic descriptions from soil and monitoring well borings indicate that anywhere from two feet to over 20 feet of fill material are present at the Plant. The fill deposits are approximately five feet thick along the northern boundary of the Plant and increase to more than 20 feet in thickness along the axis of the filled former creekbed and meanders of Frankford Creek. A map of approximate fill thickness is included as Figure 3-5 of the Phase I RFI Report (1992). Interpretations of the Phase II RFI soil and monitoring well borings and of the older Plant test borings did not result in significant changes in the interpretation of the thickness or distribution of the fill deposits shown in the Phase I Report.



The actual thickness of saprolite and weathered bedrock throughout the site is difficult to determine with accuracy. Most of the foundation test borings penetrated from one or two feet to over 20 feet of weathered or decomposed bedrock. Several of the borings were stopped due to drilling or sampling refusal, a fairly good indication of unweathered or only slightly weathered rock. However, most of the borings were completed before refusal depth was reached. Furthermore, refusal depths in a given material are subject to change with different drilling or sampling techniques and the criteria used to define refusal (e.g., the number of hammer blows exceeded while driving the sampler for a given distance). The distinction between weathered or decomposed bedrock and unweathered rock can also be somewhat subjective and may vary depending upon the individual driller or geologist describing the samples. Very few of the foundation test borings distinguished between the residual clay type of saprolite and other weathered or decomposed bedrock. In those that do, the residual clay saprolite generally has a thickness of two to three feet or less.

All of the Phase I and II borings that reached bedrock encountered on the order of one foot or less of residual clay saprolite before reaching sampler or auger refusal. The saprolite was a white, light-greenish gray, or gray and black, very micaceous, firm, sticky clay with numerous quartz grains and traces of garnet or pyrite. The texture and mineralogy were of an extensively weathered mica schist or gneiss.

### **3.5 HYDROGEOLOGY**

Descriptions of the regional hydrogeology in the vicinity of the Plant are excerpted from "Groundwater Resources of the Coastal Plain Area of Southeastern Pennsylvania" (Greenman, et al., 1961). Descriptions of site-specific hydrogeology use information from the same reference in conjunction with the site-specific geological interpretations and information obtained during the Phase I and II investigations.

#### **3.5.1 Regional Hydrogeology**

Groundwater in the unconsolidated sediments of the area may occur under either water table or artesian conditions. The water-table system is made up of unconfined and semiartesian aquifers having common hydraulic head, similar hydrogeologic properties, and local sources of recharge. Groundwater in most of the Pleistocene and Recent age deposits as well as the Old Bridge sand member of the Raritan Formation occurs under water-table conditions. Groundwater in portions of the Farrington and Sayreville sand members of the Raritan Formation where the lower and middle clay members are absent or discontinuous may also occur under water-table conditions. Artisan conditions do occur locally within Pleistocene deposits where they are overlain by silt and clay deposits of Recent age, but these aquifers are still considered to be part of the overall water-table system.

The Pleistocene alluvial deposits are part of the water-table system and comprise the most extensive aquifer in the area of the Plant. The water-bearing properties of the sediments are highly variable due to their heterogeneous lithology. The highly permeable sand and gravel beds are capable of yielding large quantities of groundwater to wells. The Pleistocene sediments are favorably situated with respect to recharge and are thus subject to contamination from the surface. The Pleistocene deposits locally contain water under artisan conditions where they are overlain by less permeable confining beds of Recent age.

Sediments of Recent geological age are generally fine grained and less permeable than the sediments comprising the aquifers. Consequently, they are unimportant as a source of groundwater and, where present, constitute a leaky confining bed that tends to restrict the free exchange of water between the surface and groundwater bodies.

The artisan aquifer system comprises a really extensive confined aquifers with distinct hydraulic and hydrogeologic properties and with relatively remote sources of recharge. The artisan aquifer system is represented in Pennsylvania by the Farrington and Sayreville sand members of the Raritan Formation, along with the overlying lower and middle clay members. This aquifer system extends from a high-level recharge area east of Trenton, New Jersey southward and westward to low-level discharge areas in the Delaware River valley. Hydraulic continuity of this aquifer system depends upon the physical continuity of the Raritan Formation members that comprise it.

The Farrington sand member of the Raritan Formation is a productive aquifer when present and of sufficient thickness. It generally functions as a separate hydrologic unit of the artisan aquifer system and is insulated from overlying water-bearing beds and surface water sources. A hypothetical representation of the piezometric surface of the Farrington sand, in the absence of pumping well influences, indicates a hydraulic gradient toward the northwest in the area of the Plant. This representation also indicates that the Farrington sand aquifer discharges groundwater to the overlying water-table aquifer system in areas near the Plant where it is not confined by the lower and middle clay members (Greenman, et al., 1961).

Whenever present, the lower and middle clay members of the Raritan Formation represent the upper confining layer of the artisan aquifer system of the area. This layer limits the movement of groundwater between the Farrington sand member and the water-bearing zones above. The Old Bridge sand, Sayreville sand, and upper clay members of the Raritan Formation are interpreted to be absent in the area of the Plant (Greenman, et al., 1961).

The crystalline bedrock and residual clay or saprolite that underlie the unconsolidated Coastal Plain sediments probably serve mainly as a lower confining layer retarding groundwater movement out of the overlying aquifers. Groundwater generally occurs under water-table conditions in outcrop areas of the bedrock. Artisan conditions may occur locally where open fractures underlie the saprolite or the confining beds of the unconsolidated sediments. The basement bedrock complex can be expected to reliably yield small to moderate quantities of groundwater.

### **3.5.2 Site Hydrogeology**

Site hydrogeological interpretations were made using data obtained from approximately 70 piezometers, recovery wells, and monitoring wells; observations, measurements, and other information collected for sewer lines and other underground utilities at the Plant; and groundwater quality field observations and analytical data collected during the Phase II RFI and previous investigations. These data were used in conjunction with the site geological interpretation and the regional hydrogeologic setting to create an interpretation that is consistent with all the currently available information.

#### **3.5.2.1 Available Well Information**

Twenty temporary shallow piezometers (P-101 through P-120), 20 shallow monitoring wells (MW-104 through MW-123), and six deep monitoring wells (MW-301 through MW-306) were installed during the Phase II RFI field work. Ten shallow LNAPL monitoring wells (MW-201 through MW-210) were previously installed at the Plant during the conceptual design investigation for free-phase product recovery (Halliburton NUS, February 1993). Three shallow monitoring wells (MW-101, MW-102, and MW-103) were previously installed during the Phase I RFI field work at the Plant. The construction and condition of six groundwater recovery wells (R-1 through R-6) and five existing piezometers (P-1 through P-5) were also evaluated during the Phase I RFI. The locations of all monitoring wells, recovery wells, and piezometers are shown on Figures 2-1, 2-2, and 2-5. A summary of construction, completion, and elevation data for these wells and piezometers is contained in Table 3-1.

More specific installation and completion details for the Phase II RFI monitoring wells, including backfill materials and depths, borehole dimensions, etc., are shown in the monitoring well construction sheets included in Appendix C of this report. Monitoring well construction sheets with the same information for wells MW-201 through MW-210 are included in Appendix B of the "Final Report of the Conceptual Design Study for Free-Phase Product Recovery" (Halliburton NUS, February 1993). Monitoring well construction sheets with the same information for wells MW-101, MW-102, and MW-103 are included in Appendix C of the "Phase I RCRA Facility Investigation Report" (Halliburton NUS, May 1992). More detailed descriptions of the recovery wells' construction are provided later in this section.

**TABLE 3-1**  
**CONSTRUCTION DETAILS FOR WELLS AND PIEZOMETERS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Well or Piezometer Number	Date Installed	Previous Designation	Casing Material	Casing Inner Diameter (inches)	Well Completion	Total Depth (feet)	Reference Point and Elevation (feet MSL) for Water-Level Measurements
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**PIEZOMETERS**

P-1	unknown	unknown	PVC	1.25	unknown	approx. 15	Top of Casing . . . . . unknown
P-2	January 1983	B-3	steel	2	unknown	16.7	Top of Casing . . . . . 10.83
P-3	January 1983	B-1	steel	2	unknown	15.95	Top of Casing . . . . . 10.81
P-4	January 1983	G-3	steel	2	unknown	14.2	Top of Casing . . . . . 8.97
P-5	December 23, 1982	West Well	steel	2	unknown	8.7	Top of Casing . . . . . 10.33
P-101	June 7, 1993	P-101	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 8.55
P-102	June 7, 1993	P-102	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 7.87
P-103	June 7, 1993	P-103	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 8.32
P-104	June 7, 1993	P-104	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 8.86
P-105	June 7, 1993	P-105	galvanized steel	1.25	screened 7 to 10 feet <sup>(1)</sup>	10	Top of Casing . . . . . 13.02
P-106	June 7, 1993	P-106	galvanized steel	1.25	screened 7.5 to 10.5 feet <sup>(1)</sup>	10.5	Top of Casing . . . . . 15.19
P-107	June 7, 1993	P-107	galvanized steel	1.25	screened 8 to 11 feet <sup>(1)</sup>	11	Top of Casing . . . . . 11.02
P-108	June 7, 1993	P-108	galvanized steel	1.25	screened 3.5 to 6.5 feet <sup>(1)</sup>	6.5	Top of Casing . . . . . 10.31
P-109	June 7, 1993	P-109	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 11.06
P-110	June 7, 1993	P-110	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 10.17
P-111	June 7, 1993	P-111	galvanized steel	1.25	screened 7.5 to 10.5 feet <sup>(1)</sup>	10.5	Top of Casing . . . . . 15.07

**TABLE 3-1 (CONTINUED)**  
**CONSTRUCTION DETAILS FOR WELLS AND PIEZOMETERS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 2 of 5**

Well or Piezometer Number	Date Installed	Previous Designation	Casing Material	Casing Inner Diameter (inches)	Well Completion	Total Depth (feet)	Reference Point and Elevation (feet MSL) for Water-Level Measurements
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**PIEZOMETERS**

P-112	June 7, 1993	P-112	galvanized steel	1.25	screened 7.75 to 10.75 feet <sup>(1)</sup>	10.75	Top of Casing . . . . . 14.18
P-113	June 7, 1993	P-113	galvanized steel	1.25	screened 7.25 to 10.25 feet <sup>(1)</sup>	10.25	Top of Casing . . . . . 17.00
P-114	June 8, 1993	P-114	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 9.98
P-115	June 8, 1993	P-115	galvanized steel	1.25	screened 2 to 5 feet <sup>(1)</sup>	5	Top of Casing . . . . . 9.95
P-116	June 8, 1993	P-116	galvanized steel	1.25	screened 3 to 6 feet <sup>(1)</sup>	6	Top of Casing . . . . . 8.61
P-117	June 8, 1993	P-117	galvanized steel	1.25	screened 9.5 to 12.5 feet <sup>(1)</sup>	12.5	Top of Casing . . . . . 14.94
P-118	June 8, 1993	P-118	galvanized steel	1.25	screened 9.75 to 12.75 feet <sup>(1)</sup>	12.75	Top of Casing . . . . . 10.04
P-119	June 8, 1993	P-119	galvanized steel	1.25	screened 9.75 to 12.75 feet <sup>(1)</sup>	12.75	Top of Casing . . . . . 18.27
P-120	June 8, 1993	P-120	galvanized steel	1.25	screened 5 to 8 feet <sup>(1)</sup>	8	Top of Casing . . . . . 9.09

**RECOVERY WELLS**

R-1	1983	R-1	galvanized steel	18	(2)	18.3	Ground <sup>(3)</sup> . . . . . 9.71
R-2	1983	R-2	galvanized steel	18	(2)	unknown	Ground <sup>(3)</sup> . . . . . 9.26
R-3	1983	R-3	galvanized steel	18	(2)	unknown	Ground <sup>(3)</sup> . . . . . 9.11
R-4	June 27, 1984	R-4	galvanized steel	26	(2)	20	Ground <sup>(4)</sup> . . . . . 11.35
R-5	June 17, 1985	R-5	concrete	48	(2)	16	Ground <sup>(4)</sup> . . . . . 14.84
R-6	July 1990	R-6	unknown	48	(2)	13.5	Ground <sup>(4)</sup> . . . . . 10.95

**TABLE 3-1 (CONTINUED)**  
**CONSTRUCTION DETAILS FOR WELLS AND PIEZOMETERS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 3 of 5**

Well or Piezometer Number	Date Installed	Previous Designation	Casing Material	Casing Inner Diameter (inches)	Well Completion	Total Depth (feet)	Reference Point and Elevation (feet MSL) for Water-Level Measurements
<b>MONITORING WELLS</b>							
MW-101	January 16, 1992	MW-101	stainless steel	2	screened 5 to 15 feet <sup>(5)</sup>	15	Top of Inner Casing . . . 10.89
MW-102	January 17, 1992	MW-102	stainless steel	2	screened 12 to 22 feet <sup>(5)</sup>	22	Top of Inner Casing . . . 18.26
MW-103	January 17, 1992	MW-103	stainless steel	2	screened 5 to 15 feet <sup>(5)</sup>	15	Top of Inner Casing . . . . 7.46
MW-104	August 3, 1993	OSS-6	stainless steel	2	screened 3.5 to 13.5 feet <sup>(5)</sup>	13.5	Top of Inner Casing . . . . 7.46
MW-105	August 4, 1993	OSS-3	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . . 9.02
MW-106	August 4, 1993	OSS-2	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . 12.53
MW-107	August 5, 1993	OSS-7	stainless steel	2	screened 3.5 to 13.5 feet <sup>(5)</sup>	13.5	Top of Inner Casing . . . 8.90
MW-108	August 6, 1993	OSS-1	stainless steel	2	screened 10.5 to 20.5 feet <sup>(5)</sup>	20.5	Top of Inner Casing . . . 15.64
MW-109	August 6, 1993	OSS-11	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . . 9.90
MW-110	August 9, 1993	OFS-1	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . 11.24
MW-111	August 9, 1993	OSS-9	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . . 8.33
MW-112	August 10, 1993	OFS-4	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . 13.16
MW-113	August 10, 1993	OSS-10	stainless steel	2	screened 5.75 to 15.75 feet <sup>(5)</sup>	15.75	Top of Inner Casing . . . 11.45
MW-114	August 11, 1993	OFS-6	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . . 9.79
MW-115	August 11, 1993	OSS-13	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . 11.70
MW-116	August 12, 1993	OFS-7	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . 11.31

**TABLE 3-1 (CONTINUED)**  
**CONSTRUCTION DETAILS FOR WELLS AND PIEZOMETERS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 4 of 5**

Well or Piezometer Number	Date Installed	Previous Designation	Casing Material	Casing Inner Diameter (inches)	Well Completion	Total Depth (feet)	Reference Point and Elevation (feet MSL) for Water-Level Measurements
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**MONITORING WELLS**

MW-117	August 12, 1993	OSS-8	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . . . 8.40
MW-118	August 13, 1993	OSS-4	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . . . 13.75
MW-119	August 16, 1993	OSS-5	stainless steel	2	screened 3.5 To 13.5 feet <sup>(5)</sup>	13.5	Top of Inner Casing . . . . . 9.22
MW-120	September 1, 1993	OFS-3	stainless steel	2	screened 3.25 to 13.25 feet <sup>(5)</sup>	13.25	Top of Inner Casing . . . . . 8.54
MW-121	September 1, 1993	OFS-5	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . . . 11.25
MW-122	September 2, 1993	OFS-2	stainless steel	2	screened 5.25 to 15.25 feet <sup>(5)</sup>	15.25	Top of Inner Casing . . . . . 10.65
MW-123	September 10, 1993	OSS-12	stainless steel	2	screened 5.5 to 15.5 feet <sup>(5)</sup>	15.5	Top of Inner Casing . . . . . 7.06
MW-201	November 17, 1992	MW-201	stainless steel	4	screened 5.5 to 10.5 feet <sup>(6)</sup>	10.5	Top of Inner Casing . . . . . 7.98
MW-202	November 18, 1992	MW-202	stainless steel	4	screened 5.25 to 15.25 feet <sup>(6)</sup>	15.25	Top of Inner Casing . . . . . 12.53
MW-203	November 19, 1992	MW-203	stainless steel	4	screened 5.25 to 15.25 feet <sup>(6)</sup>	15.25	Top of Inner Casing . . . . . 12.46
MW-204	November 20, 1992	MW-204	stainless steel	4	screened 5.25 to 12.75 feet <sup>(6)</sup>	12.75	Top of Inner Casing . . . . . 9.01
MW-205	November 20, 1992	MW-205	stainless steel	4	screened 5.5 to 15.5 feet <sup>(6)</sup>	15.5	Top of Inner Casing . . . . . 12.59
MW-206	November 23, 1992	MW-206	stainless steel	4	screened 5.75 to 13.25 feet <sup>(6)</sup>	13.25	Top of Inner Casing . . . . . 10.68

**TABLE 3-1 (CONTINUED)**  
**CONSTRUCTION DETAILS FOR WELLS AND PIEZOMETERS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 5 of 5**

Well or Piezometer Number	Date Installed	Previous Designation	Casing Material	Casing Inner Diameter (inches)	Well Completion	Total Depth (feet)	Reference Point and Elevation (feet MSL) for Water-Level Measurements
<b>MONITORING WELLS</b>							
MW-207	November 23, 1992	MW-207	stainless steel	4	screened 5.75 to 13.25 feet <sup>(6)</sup>	13.25	Top of Inner Casing . 10.86
MW-208	November 24, 1992	MW-208	stainless steel	4	screened 5.5 to 13 feet <sup>(6)</sup>	13	Top of Inner Casing . 11.56
MW-209	November 25, 1992	MW-209	stainless steel	4	screened 3 to 10.5 feet <sup>(6)</sup>	10.5	Top of Inner Casing . . 8.65
MW-210	November 30, 1992	MW-210	stainless steel	4	screened 5.25 to 12.75 <sup>(6)</sup>	12.75	Top of Inner Casing . 11.67
MW-301	September 9, 1993	DW-2	stainless steel	2	screened 35.5 to 40.5 <sup>(5)</sup>	40.5	Top of Inner Casing . . 7.26
MW-302	August 24, 1993	DW-5	stainless steel	2	screened 35.5 to 45.5 <sup>(5)</sup>	45.5	Top of Inner Casing . . 8.41
MW-303	August 25, 1993	DB-2	stainless steel	2	screened 37.75 to 42.75 feet <sup>(5)</sup>	42.75	Top of Inner Casing . 11.04
MW-304	August 26, 1993	DW-4	stainless steel	2	screened 33.25 to 38.25 feet <sup>(5)</sup>	38.25	Top of Inner Casing . 11.94
MW-305	September 14, 1993	DW-1	stainless steel	2	screened 37.5 to 42.5 feet <sup>(5)</sup>	42.5	Top of Inner Casing . . 9.25
MW-306	September 20, 1993	DW-3	stainless steel	2	screened 35.25 to 40.25 feet <sup>(5)</sup>	40.25	Top of Inner Casing . 7.20

- (1) 1.25-inch-diameter perforated galvanized steel pipe covered with stainless-steel screen and fitted with a drive point
- (2) Refer to text for description of recovery well completion
- (3) Concrete surface adjacent to manhole cover on northern side
- (4) Top of steel manhole frame adjacent to northern side of manhole cover
- (5) Johnson 0.010 slot, 2-inch-diameter, stainless-steel
- (6) Johnson 0.010 slot, 4-inch-diameter, stainless-steel



Due to recent construction activities, the depths recorded on the MW-102 monitoring well construction sheet (Halliburton NUS, May 1992) are now too short by approximately two feet when referenced to the present ground surface. This change is a result of the addition of a 2.15-foot section to the well casing and the emplacement of about two feet of clean fill atop the ground surface in the MW-102 area.

The total depth and reference point elevation of piezometer P-1, although known during the Phase I RFI, are now listed as approximate and unknown, respectively. This is because changes were made to the top of casing and piezometer cap during construction of the nearby high-purity phenol unit.

Groundwater recovery wells R-1, R-2, and R-3 are located in the caustic spill area of the site. All three are constructed of galvanized-steel pipe or casing. Forty-eight evenly spaced 3/8-inch circular perforations are present around the circumference of the casing at regularly spaced, three-inch-depth increments from the ground surface to the visible water level in each well (Halliburton NUS, May 1992). The remaining construction details are presented in Table 3-1. The total depths of wells R-2 and R-3 were not measured to avoid interfering with the water-level probes or pumps.

Groundwater recovery wells R-4, R-5, and R-6 are located within the LNAPL layer area near the center of the Plant. Data for these wells were obtained from the RFI Plan (NUS, 1991), from blueprints of the wells' construction provided by Allied, and from field measurements taken during the Phase I RFI field work. The following paragraphs excerpted from the RFI Plan (NUS, 1991) summarize the completion and construction details of these recovery wells. Additional information is supplied in Table 3-1.

Recovery well R-4 was installed on June 27, 1984. It is located adjacent to Phenol Unit No. 2 (CP2) on Main Street west of Wakeling Street (see Figure 2-5). R-4 is 20 feet deep, with 15 feet of slotted 26-inch-diameter screen placed in a 36-inch borehole packed in Morie filter sand. When the groundwater reaches a predetermined level, a float switch is closed and pumping is initiated.

Recovery well R-5 was installed on June 17, 1985. It is located on Wakeling Street adjacent to the CP2 tank farm. The R-5 well casing is 16 feet deep. Two lateral extensions set at 45-degree angles intersect the 58-inch outside-diameter well casing. The lateral extensions are 10-inch-diameter Schedule 80 polyvinyl chloride (PVC) pipe, with 1.2-inch perforations on the top half of the pipe. The extensions are on a slope to facilitate flow to the well casing. When groundwater reaches a predetermined level, a float switch is closed and pumping is initiated.

Based on B&R Environmental's experience, it is possible that the PVC laterals have been degraded by chemicals in the groundwater. This could explain why this well only produces approximately one gpm.

Recovery well (R-6) was completed in July 1990. R-6 is located adjacent to CP2 on Main Street west of Wakeling Street. The R-6 well casing is 13 feet, six inches in total depth. Two lateral extensions (100 feet and 85 feet long) lie parallel to M sewer along Main and G Streets, respectively, and intersect the 48-inch inside-diameter well casing. The lateral extensions are 10-inch-diameter Schedule 80 vitrified clay pipe, with 1.2-inch perforations on the top half of the pipe. The laterals are on a 0.1-inch-per-foot slope to facilitate flow to the well casing. When the groundwater reaches a predetermined level, a float switch is closed and pumping is initiated.

### **3.5.2.2 Shallow Unconfined Aquifer**

The shallow aquifer at the site is composed of the fill deposits and the sand and gravel deposits. Groundwater in this aquifer is unconfined (i.e., occurs under water-table conditions). In the areas of the site containing recent silt and clay deposits, the shallow aquifer consists entirely of saturated fill deposits, and extends from the water-table down to the top of the recent silt and clay layer. In the other areas of the site, the shallow aquifer consists of either saturated fill deposits and sand and gravel deposits or solely the sand and gravel deposits and extends from the water-table surface down to the top of the saprolite and bedrock or the older silt and clay deposits.

The recent silt and clay deposits, where present, are not expected to function as part of the shallow water-table aquifer, but rather as a confining layer at the base of the aquifer. The principal exception to this would be those areas where the recent silt and clay deposits contain fine-grained sand and sandy layers that come in contact with the overlying saturated fill deposits. These sandy layers have been observed in places within the former Frankford Creek channel and meanders and are expected to function as part of the shallow aquifer. The saprolite and bedrock underlying the shallow aquifer are also expected to act as a lower confining layer to this aquifer.

The hydraulic properties of the shallow water table aquifer are expected to vary significantly throughout the site based on the heterogeneous nature of the fill deposits and the sand and gravel deposits that comprise the aquifer. This is evidenced by the wide range of hydraulic conductivity measurements, shown in Table 3-2, that were obtained from wells within the shallow aquifer (all monitoring wells except MW-301, MW-302, MW-303, and MW-305 are completed in the water-table aquifer). The hydraulic conductivity values range from a low of  $2.0 \times 10^{-7}$  centimeters per second (cm/sec) in the silty, clayey fill deposits of MW-104 to a high of  $8.7 \times 10^{-2}$  cm/sec in the sand and gravel deposits of MW-102. Hydraulic conductivity calculations are presented in Appendix D. No pumping tests were run on wells in the shallow aquifer; therefore, aquifer properties such as transmissivity and storativity cannot be estimated.

**TABLE 3-2**  
**SUMMARY OF HYDRAULIC CONDUCTIVITY MEASUREMENTS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Well Number	Hydraulic Conductivity	
	cm/sec	feet per day
MW-101	$1.4 \times 10^{-2}$	40
MW-102	$8.7 \times 10^{-2}$	247
MW-103	$1.7 \times 10^{-3}$	5
MW-104	$2.0 \times 10^{-7}$	0.0006
MW-105	$2.2 \times 10^{-5}$	0.06
MW-106	$4.5 \times 10^{-2}$	128
MW-107	- NA -	- NA -
MW-108	$7.9 \times 10^{-3}$	22
MW-109	$5.8 \times 10^{-3}$	164
MW-110	$6.8 \times 10^{-3}$	19
MW-111	$9.2 \times 10^{-6}$	0.03
MW-112	$1.0 \times 10^{-3}$	3
MW-113	$1.7 \times 10^{-3}$	5
MW-114	$4.7 \times 10^{-3}$	13
MW-115	$7.1 \times 10^{-3}$	20
MW-116	$1.1 \times 10^{-4}$	0.3
MW-117	$9.4 \times 10^{-4}$	3
MW-118	$7.1 \times 10^{-3}$	20
MW-119	$1.4 \times 10^{-4}$	0.4
MW-120	$2.9 \times 10^{-3}$	8
MW-121	$6.0 \times 10^{-4}$	2

\* For unknown reasons, pressure transducers did not function properly in well MW-107; therefore, hydraulic conductivity measurements are not available in this well.

**TABLE 3-2**  
**SUMMARY OF HYDRAULIC CONDUCTIVITY MEASUREMENTS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 2 of 2**

Well Number	Hydraulic Conductivity	
	cm/sec	feet per day
MW-122	$1.5 \times 10^{-4}$	0.4
MW-123	$1.5 \times 10^{-2}$	43
MW-202	$6.7 \times 10^{-4}$	1.9
MW-203	$2.0 \times 10^{-5}$	0.06
MW-205	$5.1 \times 10^{-5}$	0.2
MW-206	$2.4 \times 10^{-3}$	7
MW-208	$2.5 \times 10^{-2}$	71
MW-209	$3.3 \times 10^{-4}$	1
MW-210	$3.5 \times 10^{-3}$	10
MW-301	$1.5 \times 10^{-2}$	43
MW-302	$7.7 \times 10^{-4}$	2
MW-303	$3.2 \times 10^{-4}$	0.9
MW-304	$2.0 \times 10^{-2}$	57
MW-305	$8.6 \times 10^{-4}$	0.2
MW-306	$3.0 \times 10^{-2}$	85

\* For unknown reasons, pressure transducers did not function properly in well MW-107; therefore, hydraulic conductivity measurements are not available in this well.

There is a fairly consistent correlation between grain size and degree of sorting of the aquifer materials and the measured hydraulic conductivity in wells throughout the site. Generally, the more fine-grained and/or poorly sorted deposits have lower hydraulic conductivity values than those which are more coarse-grained and/or well sorted. Similar behavior was observed during development and sampling when the wells were either pumped or bailed. The fine-grained and/or poorly sorted deposits had the lowest water yields of only a fraction of a gallon per minute while the more coarse-grained and/or well-sorted deposits had higher water yields of up to several gallons per minute.

The depth and elevation of the shallow water-table surface were measured in all the readily accessible monitoring wells recovery wells and piezometers on two separate occasions during the Phase II RFI. In wells or piezometers containing free-phase LNAPL, an adjusted groundwater elevation was calculated using the measured thickness of the LNAPL layer and the specific gravity of the LNAPL in that area taken from the "Report of Free-Phase Product Recovery System Pilot Testing and Associated Work" (B&R Environmental, July 1993). The elevations of reference points for all wells and piezometer were surveyed with respect to U.S.G.S. MSL datum (USGS MSL Datum = Allied Frankford Plant Datum + 6.071 feet; Philadelphia City Datum = Allied Frankford Plant Datum + 0.195 feet).

During the first complete round of water-level measurements, all readings were taken within a time span of approximately 3.5 hours on June 10, 1993 during stable weather conditions. The results of these water-level elevation measurements are summarized in Table 3-3, and the adjusted groundwater elevations are plotted and contoured on Figure 3-13. These water levels do not include the Phase II RFI monitoring wells, which were not installed until later in the investigation. The water-level elevation of the Frankford Inlet was not included because the influence of surface water tidal fluctuations on the shallow water-table aquifer had not yet been determined.

During the second complete round of water-level measurements, all readings were taken within a time span of approximately six hours on October 15, 1993 during stable weather conditions. The results of these water-level elevation measurements are summarized in Table 3-4, and the adjusted groundwater elevations for the shallow aquifer are plotted and contoured on Figure 3-14. The water-level elevation of the Frankford Inlet was obtained near the beginning and end of this round of water-level measurements in order to quantify the tidal fluctuation of nearby surface water bodies during this time span. Those wells and piezometers in which water levels are known to be influenced by tidal fluctuations (discussed later in Section 3.5.2.6) were all measured in as short a time possible near low tide at the beginning of the round.

**TABLE 3-3**  
**JUNE 10, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water-Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water-Level Depth Below Reference Point	Adjusted Groundwater Elevation (feet, MSL)
MW-101	11:30 AM	10.89	6.22	----	----	4.67
MW-102	1:35 PM	16.11	- NA <sup>(3)</sup>	----	----	- NA <sup>(3)</sup>
MW-103	12:46 PM	7.46	4.56	----	----	2.90
MW-201	12:42 PM	7.98	6.48	----	----	1.50
MW-202	11:25 AM	12.53	8.98	7.56	7.73	4.80
MW-203	11:27 AM	12.46	7.71	7.65	7.66	4.80
MW-204	12:37 PM	9.01	4.82	----	----	4.19
MW-205	11:20 AM	13.59	9.11	8.95	8.96	4.63
MW-206	1:08 PM	10.68	5.73	----	----	4.95
MW-207	1:12 PM	10.86	6.14	5.88	5.89	4.97
MW-208	1:27 PM	11.56	- NA <sup>(4)</sup>	- NA <sup>(4)</sup>	- NA <sup>(4)</sup>	- NA <sup>(4)</sup>
MW-209	12:33 PM	8.65	3.22	3.20	3.20	5.45
MW-210	1:25 PM	11.67	7.33	6.69	6.74	4.93
P-1	11:49 AM	- NA <sup>(5)</sup>	8.80	- NA <sup>(5)</sup>	- NA <sup>(5)</sup>	- NA <sup>(5)</sup>
P-2	12:08 PM	10.83	5.13	---	---	5.70
P-3	12:07 PM	10.81	4.98	---	---	5.83
P-4	12:05 PM	8.97	3.47	---	---	5.50

**TABLE 3-3 (CONTINUED)**  
**JUNE 10, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**Page 2 of 3**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water-Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water-Level Depth Below Reference Point	Adjusted Groundwater Elevation (feet, MSL)
P-5	12:03 PM	10.33	2.46	---	---	7.87
P-101	10:53 AM	8.55	3.92	---	---	4.63
P-102	10:47 AM	7.87	4.02	---	---	3.85
P-103	10:49 AM	8.32	2.69	---	---	5.63
P-104	11:06 AM	8.86	6.24	---	---	2.62
P-105	12:23 PM	13.02	9.72	---	---	3.30
P-106	12:53 PM	15.19	12.43	---	---	2.76
P-107	2:07 PM	11.02	8.52	---	---	2.50
P-108	12:51 PM	10.31	3.46	---	---	6.85
P-109	12:55 PM	11.06	4.22	---	---	6.84
P-110	1:00 PM	10.17	6.50	---	---	3.67
P-111	12:58 PM	15.07	10.64	---	---	4.43
P-112	10:56 AM	14.18	10.04	---	---	4.14
P-113	10:59 AM	17.00	12.69	---	---	4.31
P-114	11:08 AM	9.98	8.18	---	---	1.80
P-115	11:10 AM	9.95	8.34	---	---	1.61
P-116	12:27 PM	8.61	4.31	---	---	4.30

**TABLE 3-3 (CONTINUED)**  
**JUNE 10, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**Page 3 of 3**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water-Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water-Level Depth Below Reference Point	Adjusted Groundwater Elevation (feet, MSL)
P-117	1:15 PM	14.94	9.95	---	---	4.99
P-118	12:20 PM	10.04	11.95	---	---	-1.91
P-119	11:16 AM	18.27	13.10	---	---	5.17
P-120	11:03 AM	9.09	5.40	---	---	3.69
R-1	12:16 PM	9.71	4.20	---	---	5.51
R-2	12:14 PM	9.26	2.80	---	---	6.46
R-3	12:12 PM	9.11	3.07	---	---	6.04
R-4	11:37 AM	11.36	17.28	16.65	16.69	-5.33
R-5	11:48 AM	14.84	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>
R-6	11:43 AM	10.96	7.77	7.49	7.51	3.45

- (1) Dashed lines signify no free-phase LNAPL was found in the well; therefore, adjustments of water levels were not necessary.
- (2) Water levels were adjusted using the measured thickness of the LNAPL layer and the LNAPL-specific gravity measured previously for that area.
- (3) Well was covered by clean fill. Water-level depths and elevations are not available.
- (4) An LNAPL recovery pump was installed and running in the well. Water and LNAPL depths and elevations were not available.
- (5) The top of the piezometer was modified by recent construction. The elevations of the reference point, LNAPL, and water-level elevations were not available. The LNAPL depth is not available because the interface probe will not fit in this piezometer.
- (6) Access for LNAPL and water-level depth measurements was not available.



**TABLE 3-4**  
**OCTOBER 15, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Groundwater Elevation (feet, MSL)
MW-101	12:26 PM	10.89	6.06	---	---	4.83
MW-102	12:49 PM	18.26	12.86	---	---	5.40
MW-103	10:55 AM	7.46	4.61	---	---	2.85
MW-104	8:44 AM	7.46	4.51	---	---	2.95
MW-105	10:30 AM	9.02	2.87	---	---	6.15
MW-106	10:36 AM	12.53	8.46	---	---	4.07
MW-107	10:43 AM	8.90	4.09	---	---	4.81
MW-108	12:57 PM	15.64	10.69	---	---	4.95
MW-109	8:54 AM	9.90	8.50	---	---	1.40
MW-110	2:05 PM	11.24	6.61	---	---	4.63
MW-111	9:13 AM	8.33	4.39	---	---	3.94
MW-112	1:55 PM	13.16	10.37	---	---	2.79
MW-113	8:50 AM	11.45	9.67	---	---	1.78
MW-114	1:45 PM	9.79	7.17	---	---	2.62
MW-115	9:02 AM	11.70	9.60	---	---	2.10
MW-116	1:33 PM	11.31	9.21	---	---	2.10
MW-117	9:30 AM	8.40	5.97	---	---	2.43
MW-118	11:48 AM	13.75	8.80	---	---	4.95
MW-119	11:53 AM	9.22	1.76	---	---	7.46
MW-120	2:20 PM	8.54	3.22	---	---	5.32
MW-121	2:10 PM	11.25	6.27	---	---	4.98

**TABLE 3-4 (CONTINUED)**  
**OCTOBER 15, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 2 of 4**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Groundwater Elevation (feet, MSL)
MW-122	2:00 PM	10.65	4.85	---	---	5.80
MW-123	8:33 AM	7.06	7.48	---	---	-0.42
MW-201	11:56 AM	7.98	6.55	---	---	1.43
MW-202	12:32 PM	12.53	9.52	7.36	7.63	4.90
MW-203	12:33 PM	12.46	7.62	7.54	7.55	4.91
MW-204	11:59 AM	9.01	4.37	---	---	4.64
MW-205	12:38 PM	13.59	9.23	8.80	8.84	4.75
MW-206	11:35 AM	10.68	5.67	---	---	5.01
MW-207	11:38 AM	10.86	6.71	5.78	5.83	5.03
MW-208	12:13 PM	11.56	7.65	6.57	6.65	4.91
MW-209	12:03 PM	8.65	2.74	2.63	2.64	6.01
MW-210	12:15 PM	11.67	7.73	6.66	6.74	4.93
MW-301	8:42 AM	7.26	5.25	---	---	2.01
MW-302	9:16 AM	8.41	5.78	---	---	2.63
MW-303	11:13 AM	11.04	8.94	---	---	2.10
MW-304	9:05 AM	11.94	9.85	---	---	2.09
MW-305	12:10 PM	9.25	6.03	---	---	3.22
MW-306	8:36 AM	7.20	7.69	---	---	-0.49
P-1	12:45 PM	- NA <sup>(3)</sup>	8.34	- NA <sup>(3)</sup>	- NA <sup>(3)</sup>	- NA <sup>(3)</sup>
P-2	9:45 AM	10.83	4.56	---	---	6.27
P-3	9:47 AM	10.81	4.60	---	---	6.21

**TABLE 3-4 (CONTINUED)**  
**OCTOBER 15, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 3 of 4**

Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Groundwater Elevation (feet, MSL)
P-4	9:40 AM	8.97	3.38	---	---	5.59
P-5	9:36 AM	10.33	3.71	---	---	6.62
P-101	1:13 PM	8.55	4.08	---	---	4.47
P-102	NM <sup>(5)</sup>	7.87	- NA <sup>(4)</sup>	---	---	- NA <sup>(4)</sup>
P-103	10:20 AM	8.32	3.74	---	---	4.58
P-104	10:02 AM	8.86	4.13	---	---	4.73
P-105	9:21 AM	13.02	9.08	---	---	3.94
P-106	11:04 AM	15.19	12.43	---	---	2.76
P-107	10:50 AM	11.02	8.48	---	---	2.54
P-108	11:00 AM	10.31	5.41	---	---	4.90
P-109	11:07 AM	11.06	3.98	---	---	7.08
P-110	NM <sup>(5)</sup>	10.17	- NA <sup>(5)</sup>	---	---	- NA <sup>(5)</sup>
P-111	11:20 AM	15.07	10.36	---	---	4.71
P-112	10:33 AM	14.18	10.17	---	---	4.01
P-113	10:38 AM	17.00	12.73	---	---	4.27
P-114	9:58 AM	9.98	5.23	---	---	4.75
P-115	10:07 AM	9.95	4.71	---	---	5.24
P-116	12:07 PM	8.61	4.05	---	---	4.56
P-117	11:46 AM	14.94	9.76	---	---	5.18
P-118	9:25 AM	10.04	9.21	---	---	0.83
P-119	12:54 PM	18.27	13.25	---	---	5.02

**TAL - 3-4 (CONTINUED)**  
**OCTOBER 15, 1993 GROUNDWATER LEVEL DATA SUMMARY**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
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Well or Piezometer Number	Measurement Time	Elevation of Reference Point (feet, MSL)	Water Level Depth Below Reference Point (feet)	LNAPL Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Water Level Depth Below Reference Point (feet) <sup>(1)(2)</sup>	Adjusted Groundwater Elevation (feet, MSL)
P-120	10:25 AM	9.09	5.41	---	---	3.68
R-1	9:51 AM	9.71	4.06	---	---	5.65
R-2	9:52 AM	9.26	2.73	---	---	6.53
R-3	9:50 AM	9.11	2.87	---	---	6.24
R-4	12:24 PM	11.36	6.87	---	---	4.49
R-5	NM <sup>(6)</sup>	14.84	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>	- NA <sup>(6)</sup>
R-6	12:20 PM	10.96	8.91	7.04	7.17	3.79
TW-2D <sup>(7)</sup>	9:40 AM	17.04	14.76	---	---	2.28
TW-29D <sup>(7)</sup>	9:55 AM	10.53	7.59	---	---	2.94
TW-14D <sup>(7)</sup>	NM <sup>(6)</sup>	NM <sup>(6)</sup>	- NA <sup>(6)</sup>	---	---	- NA <sup>(6)</sup>
FRANKFORD INLET	8:47 AM	11.74	12.95	---	---	-1.21
FRANKFORD INLET	1:00 PM	11.74	7.75	---	---	3.99

- (1) Dashed lines signify no free-phase LNAPL was found in the well; therefore, adjustment of water levels was not necessary.
- (2) Water levels were adjusted using the measured thickness of the LNAPL layer and the LNAPL-specific gravity measured previously for that area.
- (3) Top of piezometer modified by construction. Elevation of reference point not available. LNAPL depth not available because interface probe will not fit in piezometer. Water level and LNAPL level elevations not available.
- (4) Not measured. Values from MW-104 used for this location.
- (5) Not measured. Values from MW-119 used for this location.
- (6) Not measured. Well cover could not be removed. Elevation of reference point not required in absence of depth measurements.
- (7) Rohm and Haas Delaware Valley Plant deep well.

Both shallow aquifer water-table elevation maps (Figures 3-13 and 3-14) reveal a very irregular water table surface and a correspondingly complex pattern of inferred groundwater flow direction. It is possible that irregularities in the water-table surface are greater than shown and that the accuracy of Figures 3-13 and 3-14 is limited by the number and spacing of the available wells and piezometers. Therefore, both water-table elevation contour maps should be considered as the most accurate approximations using the currently available data. A comparison of the two figures also reveals that the surface of the water table and the inferred groundwater flow directions may vary significantly at different times. This implies that the two water table-elevation contour maps each represent conditions at two specific times for a dynamic shallow aquifer system in which the water-table elevations and groundwater flow pattern vary in response to changing recharge and discharge relationships. The equilibrium or representative state of the shallow aquifer with respect to water-table elevations and groundwater flow directions, or even if such a state exists, is not known. All available data indicate that significant variations in aquifer conditions exist and are controlled by a variety of interrelated surface and subsurface occurrences. No single aquifer characterization is considered to be valid for the aquifer in general.

Figures 3-13 and 3-14 indicate that the anticipated, naturally occurring water-table surface elevations and groundwater flow directions do not exist at the site. In the absence of man-made influences, the water-table surface would be a subdued replica of the land surface topography. The water-table aquifer would receive recharge directly from the infiltration of local precipitation, and groundwater flow would be from topographically higher to lower areas, with groundwater discharging to the Frankford Inlet, a nearby surface water body. Under natural conditions, a fairly uniform water-table surface, sloping gently from northwest to southeast or from southwest to northeast toward the Frankford Inlet, would be expected. Under such circumstances, there would be a fairly regular and predictable pattern of groundwater flow from higher areas within and surrounding the site toward the lower areas adjacent to the Frankford Inlet. The significant deviation of the observed water-table surface elevations and groundwater flow directions from those which would occur naturally indicates that the shallow water-table aquifer is subject to one or more man-made influences throughout a large portion of the site. Influences thought to impact the aquifer in the vicinity of the Plant are discussed below.

Areas of the Plant north of Main or Bermuda Streets and those areas south of the Frankford Inlet and former creek channel exhibit water-table elevations and groundwater flow directions similar to those that would be expected to occur naturally. The portion of the water-table aquifer with the greatest irregularity or complexity occurs between these two areas and is roughly coincident with the extent of the recent silt and clay layer. The saturated fill deposits atop the silt and clay are a geologically recent addition to the natural water-table aquifer system that is likely to have existed in this area prior to development. Where the recent silt and clay deposits probably once served to restrict the free interchange of water between the surface and the groundwater aquifer, they now serve as a lower confining unit to a water-table aquifer that was created as the fill deposits were emplaced over the past one hundred to two hundred years.

The saturated fill deposits overlying the recent silt and clay form a locally perched water-table aquifer. In this area, groundwater is restricted from moving vertically downward and flow is mainly lateral from areas of recharge to areas of discharge. The fact that the water-table elevation is significantly higher in many areas overlying the recent silt and clay layer is a result of these perched water-table conditions.

The significantly larger or steeper hydraulic gradients observed in the saturated fill deposits overlying the silt and clay versus those of the primarily sand and gravel portions of the aquifer on either side are attributed to differences in permeability. The sand and gravel deposits generally have greater hydraulic conductivities and offer less resistance to groundwater flow, resulting in lower hydraulic gradients. This is most evident in the northern portion of the Plant. Conversely, the more fine-grained and poorly sorted fill deposits are generally less permeable and are capable of supporting the steeper hydraulic gradient observed in that portion of the aquifer overlying the silt and clay deposits.

The irregular water-table elevation surface and complicated pattern of groundwater flow directions observed in Figures 3-13 and 3-14 indicate that a complex relationship between groundwater recharge and discharge exists at the site. The deviation from the expected natural hydrogeological conditions indicates that man-made sources of recharge and avenues of discharge probably control or influence much of the groundwater flow at the site. Although there are significant differences between the June 10 and October 15, 1993 water-level elevations, some of the contoured groundwater high and low areas and general flow directions appear to be consistent over time. The consistent features of the water-table elevations and groundwater flow directions are probably related to specific physical parameters of the aquifer such as thickness, elevation, hydraulic conductivity, points of discharge, and sources or areas of recharge. The temporal variations of the water-table elevations and groundwater flow directions are probably related to differences in the amount and frequency of precipitation and seasonal variations such as evapotranspiration rates.

Two of the most important sources of recharge to the water-table aquifer at the site are the direct infiltration of local precipitation and the lateral flow of groundwater into the site from hydraulically upgradient neighboring areas. Based on data from Figures 3-13 and 3-14, most of the groundwater flow into the site is from the area northwest of the Plant along I-95. Groundwater flow into the area of the site south of the Frankford Inlet and former creek channel is from the residential areas south of the Plant.

The areas of the water-table aquifer receiving the most recharge from local precipitation are those not covered by impervious structures or surfaces (see Figure 3-9). The most significant water-table recharge resulting from local precipitation is expected to occur in the large open, gravel-covered area in the southwest portion of the Plant, the former Frankford Creek channel, and the grassy "Golf Course" area of the Plant south of the former creek channel. The unpaved areas east of the employee parking lot and in the contractor lot in the southeastern corner of the Plant may also be subject to significant infiltration of precipitation.

Another potentially important source of groundwater recharge at the site is water leaking from Philadelphia Water Department (PWD) water mains under streets and within the Plant, water leaking from the fire protection system underground lines within the Plant, and water leaking out of sewer lines that are above the water-table elevation. No data are available regarding the amount or location of any leaks from PWD water mains within the site and no potential water line leaks have been identified by the Phase II RFI activities. Approximately 2,000 gallons of water per day reportedly leak from the Plant fire protection water system (Dan Davis, AlliedSignal, personal communication, September 8, 1993); however, the actual rate(s) and location(s) of the leaks are not known. No data are available to evaluate potential leakage from sewer lines above the water table. These lines are not expected to be a significant source of groundwater recharge since most of the major sewer lines occur below the water table throughout most of the Plant.

Some of the contoured higher water-table elevations occur in approximately the same locations on both the June and October measurement dates. These features are interpreted to correspond to localized areas or sources of groundwater recharge within the Plant. One of the most prominent of these water-table highs occurs beneath the tank farm in the area between piezometers P-2 and P-5, where consistently high water-table elevations are observed in spite of the pumping from recovery wells R-1, R-2, and R-3. The source or sources of recharge associated with this area are not known. Other consistent water-table highs associated with undetermined sources of groundwater recharge occur in the area near piezometers P-103 and well MW-105 and in the area near well MW-209. Another location of consistently high water-table elevations occurs in the area between piezometers P-108 and P-109 and well MW-119 (piezometer P-110 on the June 10, 1993 map) in the southwestern portion of the Plant. Either ponded water or wet soils are always present at the surface in this area just north of piezometer P-108. The high groundwater levels here are attributed to recharge from precipitation falling on this area and from a suspected leaking fire protection system line near piezometer P-108.

Several mechanisms of groundwater discharge from the water-table aquifer are interpreted to be operating at the site. The natural discharge point for the area, the Frankford Inlet, still receives groundwater discharge from portions of the Plant and from areas located south of the Plant. Any of the recovery wells R-1 through R-6, when pumping, act as groundwater discharge points. Some portions of the underground sewer lines beneath or adjacent to the Plant are also believed to be groundwater discharge points based on contoured water-table elevations and groundwater flow directions. Field measurements and observations supporting this interpretation are presented in greater detail in Section 3.5.2.7.

The data presented in Figures 3-13 and 3-14 suggest that the only significant impact on the local water-table system due to pumping results from operation of well R-6. Groundwater discharge to well R-6 is indicated by closed contours of lower groundwater elevation and inferred groundwater flow toward the well from all surrounding areas. The relatively low groundwater elevation in well R-6 (compared to the adjacent surrounding wells) is observed on a consistent basis. Low groundwater elevations in recovery well R-4 as shown on Figure 3-13 are observed only occasionally. The fact that R-6 yields and pumps much larger volumes of groundwater (approximately 30 gpm) than the other recovery wells also supports its greater importance as a point of groundwater discharge.

Water-table elevations and groundwater flow directions in the southeastern part of the Plant, although somewhat variable, show that groundwater discharge is to the Frankford Inlet. One very obvious point of groundwater discharge to the inlet is a groundwater seep on the banks of the inlet near P-114. This seep has an estimated discharge of about one gallon per minute and can be observed discharging groundwater to the inlet at all times except during high tide. Groundwater flow directions south of the inlet indicate that discharge in this area is also to the inlet and/or to another discharge point located near monitoring well MW-123. The water-table elevation in monitoring well MW-123 is below that of the inlet the majority of the time, except for periods of low tide, suggesting that another mechanism of groundwater discharge is operating in this area. The most likely possibility is that there is infiltration to a deep collector sewer line located in this area and that groundwater discharge south of the Frankford Inlet may either be to the inlet or to the deep sewer line. Possible infiltration to the deep collector sewer line near MW-123 is discussed in greater detail in Sections 3.5.2.5 and 3.5.2.7.

Two prominent groundwater discharge areas are present within the south-central portion of the Plant based on water-table elevations and groundwater flow directions from both the June and October 1993 rounds of water-level measurements. One of these areas is located in the vicinity of monitoring well MW-201 and the other is located near piezometer P-118. Based on their locations, both of these discharge points are interpreted to be a result of infiltration to sewer lines: to the E sewer near monitoring well MW-201 and either the Frankford Inlet sewer line or Deep Collector sewer line near P-118. Both these sanitary sewers discharge to the Northeast Water Pollution Control Plant (NEWPCP). The evidence for groundwater infiltration to sewer lines is discussed in greater detail in Section 3.5.2.7.



Another less prominent groundwater discharge point is indicated by water-table elevations and groundwater flow directions in the vicinity of piezometer P-120 in the northeastern part of the Plant. This discharge point is only apparent with the October 15, 1993 water-level data. Groundwater flow in the same area, based on the June 10, 1993 water level data, is toward the Frankford Inlet. It is possible that groundwater discharge in this area is through either flow toward the inlet, recharge of the deeper sand and gravel aquifer, and/or infiltration to the W sewer line and/or a city sewer line beneath the former Granite and Milnor Streets, located here.

Water-table elevations and groundwater flow directions from the October 15, 1993 round of water-level measurements indicate an apparent groundwater discharge point beyond the northwestern corner of the Plant. There are insufficient data to define the location and mechanism of such a discharge point; however, infiltration to sewer lines and recharge of the deeper sand and gravel aquifer are possible explanations.

Very approximate groundwater flow estimates were made for some of the discharge areas mapped on Figure 3-14. These estimates were made using the geometrical mean of hydraulic conductivity measurements in that area, the cross-sectional area through which groundwater must flow to the discharge point (length times estimated aquifer thickness), and the average hydraulic gradient at the point where groundwater flows through the cross-sectional area. The average linear flow velocity of the groundwater at given locations was also calculated using an assumed effective porosity of 35 percent for the heterogeneous fill and sedimentary deposits comprising the aquifer. These calculations are included in Appendix E.

Estimated shallow groundwater flow toward the south side of Frankford Inlet west of Bridge Street (see Figure 3-14) is 10,000 gallons per day (gpd) or 7.1 gallons per minute (gpm) with an average linear velocity of 0.54 feet per day (ft/day). A significant portion of this flow may be diverted to a discharge point (i.e., sewer) near MW-123 and MW-306 (see above) before reaching the inlet.

Estimated shallow groundwater flow toward the northern side of Frankford Inlet within the Plant is about 4 gpd (0.0027 gpm) with an average linear velocity of 0.00011 to 0.00078 ft/day. This extremely low velocity and flow is a result of the fine-grained nature and very low hydraulic conductivity of the fill deposits in this area and the moderate hydraulic gradient of the water table here. Groundwater discharge to the northern side of Frankford Inlet at the Plant also includes  $\pm 1.0$  gpm (estimated) from a seep on the bank of the inlet near piezometer P-114.

Estimated shallow groundwater flow to the discharge point near MW-201 (see Figure 3-14) is 1,600 gpd (1.10 gpm) with average linear velocities from 0.049 to 0.078 ft/day. The estimated shallow groundwater flow to the discharge point near P-118 is 11,000 gpd (7.7 gpm) with average linear velocities from 0.25 to 0.36 ft/day. This groundwater discharge is assumed to result from infiltration to sanitary sewer lines at both locations.

Shallow groundwater flow from within the Plant toward an apparent discharge area near the northwestern corner of the Plant (near monitoring well MW-110) is estimated to be 621 gpd (0.43 gpm) with an average linear velocity of 0.044 ft/day. This discharge may be related to sewer sanitary line infiltration. The estimated shallow groundwater flow toward Gaul Street from within the southwestern corner of the plant is 104 gpd (0.07 gpm) with an average linear velocity of 0.02 ft/day. This flow is assumed to be diverted or intercepted by the Frankford Inlet sewer line because significant levels of groundwater contamination found in upgradient wells (i.e., monitoring well MW-119) are not observed at the downgradient well locations (monitoring wells MW-111 and MW-112).

The estimated shallow groundwater flow to the discharge area near P-120 in the northeastern part of the Plant (see Figure 3-14) is 6,451 gpd (4.5 gpm) with average linear velocities ranging from 0.0016 to 0.27 ft/day. The amount of groundwater discharge at this location may vary with time and be partially related to sanitary sewer infiltration.

As mentioned previously, the water-table elevation maps of the site and the inferred groundwater flow directions are very approximate and are limited by the number and spacing of the wells and piezometer used in the interpretation. It is probable that the contours of the water-table surface and resulting flow directions are more complicated and in some areas significantly different than those of Figures 3-13 and 3-14. Evidence of this can be found by comparison of analytical results of the groundwater sampling (discussed in Section 4.0) with the inferred groundwater flow directions of Figure 3-14. For example, significant levels of groundwater contamination were observed in samples from wells MW-119 and MW-122 and are present throughout the intervening area based on field observations. One of the predicted flow directions from this area is to the southeast toward wells MW-112 and MW-111. However, no significant groundwater contamination was observed in these wells. It is apparent that different hydrogeologic conditions must exist in this area than those that are shown on Figure 3-14. However, the number and spacing of groundwater control points present are not sufficient to accurately determine the actual conditions. Furthermore given extreme complexity of the shallow water table system, an accurate determination may not be achievable at a reasonable cost. Nevertheless, the extent of shallow groundwater contamination has essentially been determined (see Section 4.0).

Shallow groundwater flow within the Plant is controlled by a complex relationship of recharge and discharge. Water-table elevations and flow patterns may vary significantly in response to the amount and frequency of precipitation and seasonal variations. However, some recharge and discharge areas and general flow patterns remain relatively consistent over time. Only shallow groundwater from the southeastern corner of the Plant and from areas south of Frankford Inlet discharges to the inlet. The majority of the shallow groundwater within the Plant flows to discharge points also within the Plant, including pumping recovery wells, suspected sanitary sewer line infiltration points, and, possibly, recharge zones for the deeper sand and gravel. Results of analytical data presented in Section 4.0 indicate that there is little or no flow of contaminated shallow groundwater beyond the Plant boundary, except for a relatively small area along Lefevre (Margaret) Street.

### 3.5.2.3 Recent Silt and Clay Aquitard

The recent silt and clay deposits at the site (Figure 3-10) are expected to function as a semiconfining layer rather than as an aquifer. Visual observations, grain size distribution analyses, water-level measurements, and available geological references indicate that these deposits have low vertical permeability and that the movement of groundwater across or within the deposits is very limited. Undisturbed vertical permeability analyses from Shelby tube samples of the recent silt and clay deposits shown below confirm the low vertical permeability of these sediments.

SOIL OR MONITORING WELL BORING	SAMPLE DEPTH (feet)	UNDISTURBED VERTICAL PERMEABILITY (cm/sec)
MW-302	19	$1.6 \times 10^{-7}$
SB-62	17	$1.1 \times 10^{-7}$
MW-305	11	$1.0 \times 10^{-7}$

Throughout its extent (see Figure 3-9), the recent silt and clay deposits are expected to greatly restrict the vertical movement of groundwater between the saturated fill deposits of the overlying shallow water-table aquifer and the sand and gravel deposits of the underlying deeper, semi-confined aquifer. Although the silt and clay layer does not completely separate the two aquifers or prevent the spread of contaminants to the deeper aquifer, it is one of the major controlling influences on groundwater flow patterns within the Plant.

As mentioned previously, the few sandy layers found within the recent silt and clay deposits may function as part of the shallow aquifer where they come in contact with the fill deposits, rather than as part of the confining layer. These sandy layers have been found to occur mainly within the filled former creek bed and creek meander.

Plant maps and drawings indicate that the recent silt and clay deposits have been penetrated by pilings at several locations throughout the Plant to support present and past structures. The actual effect that these pilings have upon the silt and clay deposits' integrity as a confining layer is unknown; however, it is possible that they have created conduits for the vertical migration of groundwater through the silt and clay. Approximately 50 RFI and foundation test borings have also completely penetrated the silt and clay deposits throughout the Plant (see Figures 3-2 and 3-10). Although the RFI deep borings were backfilled with bentonite clay and/or cement grout through the silt and clay, the backfill methods used for the foundation test borings are unknown. If these borings were randomly backfilled with only cuttings or allowed to collapse on their own, it is possible that they now act as significant conduits for the vertical movement of groundwater through the silt and clay deposits.

#### **3.5.2.4 Older Silt and Clay Aquitard**

The older silt and clay deposits at the site (see Figure 3-11) are also expected to function as a semi-confining layer rather than as an aquifer. Lithologic descriptions of the fine-grained and/or poorly sorted nature of these deposits suggest that they have low permeability and that the movement of water across or within the deposits is restricted.

Where present (see Figure 3-11), the older silt and clay deposits are expected to restrict the vertical movement of groundwater between the overlying sand and gravel deposits of the shallow water-table aquifer and either the underlying saprolite and bedrock or the relatively thin underlying sand and gravel layers. Considering the rather limited extent of the older silt and clay deposits within the Plant, they are not expected to have a significant influence on the overall site hydrogeologic conditions.

#### **3.5.2.5 Deeper Semi-Confined Aquifer**

The deeper, semi-confined aquifer at the site is composed mainly of the sand and gravel deposits that occur between the saprolite and bedrock and the recent silt and clay deposits (see Figures 3-4 through 3-8 and 3-10). Groundwater in this aquifer is partially confined by the underlying saprolite and bedrock and the overlying silt and clay deposits.

The available geological data indicate that the semi-confined sand and gravel deposits beneath the recent silt and clay are continuous, with an approximate average thickness of between five and 10 feet. The data also indicate that the semi-confined sand and gravel deposits are continuous with the sand and gravel deposits of the water-table aquifer at all locations along the edges of the recent silt and clay deposits at the Plant. Circumstances such as these have been described in Greenman, et al. (1961) as local artisan conditions. Local artisan conditions do not support widespread or regional patterns of groundwater movement because the recharge and discharge of groundwater occur locally. Although local artisan conditions do occur where the Pleistocene aquifers are overlain by recent age alluvial silt and clay, these aquifers are considered by Greenman, et al. (1961) to be part of the water-table hydraulic system. This is because the semi-confined aquifers are closely connected to outcrop areas of the same deposits, which are under water-table conditions and have local sources of recharge.

Of the six deep monitoring wells installed at the Plant, four (MW-301, MW-302, MW-303, and MW-305) are completed in the semi-confined deeper sand and gravel aquifer. The other two deep wells, MW-304 and MW-306, are completed at an equivalent depth in the basal sand and gravel of the water-table aquifer.

All the wells in the semi-confined aquifer penetrate at least 10 or more feet of the recent silt and clay confining layer, and the water level in the completed wells are significantly above the top of the sand and gravel deposits. In all four cases, there is a difference of approximately one foot or more between the piezometric surface elevation of the deeper semi-confined aquifer and the overlying water-table elevation at the same location. In each instance, the vertical hydraulic gradient between the overlying water-table aquifer and the deeper semi-confined aquifer is downward.

The hydraulic properties of the deeper semi-confined aquifer are expected to vary based on the heterogeneous nature of the sand and gravel deposits that make up the aquifer. This is supported by the range of hydraulic conductivities measured in monitoring wells MW-301, MW-302, MW-303, and MW-305, from  $8.6 \times 10^{-5}$  cm/sec to  $1.5 \times 10^{-2}$  cm/sec, as shown in Table 3-2. No pumping tests were run in wells completed in the deeper aquifer; therefore, aquifer properties such as transmissivity and storativity cannot be estimated.

Water levels in the deeper, semi-confined aquifer wells were recorded at low tide during the second Phase II RFI round of comprehensive water-level measurements. During this same round of water-level measurements, water levels in two deep wells on the Rohm & Haas Delaware Valley facility, TW-2D and TW-29D, were also measured. The two Rohm & Haas wells encountered similar lithologic conditions to those of the semi-confined aquifer at the Plant and are completed in a sand and gravel aquifer underlying recent fine-grained deposits.

The water-level elevations of the six wells completed in the semi-confined deeper aquifer (monitoring wells MW-301, MW-302, MW-303, MW-305, TW-2D, and TW-20D) are shown on Figure 3-15. Water levels for the two deeper wells in the water-table aquifer (MW-304 and MW-306) and for several additional wells in the water-table aquifer adjacent to the semi-confined aquifer are also shown. The water-level elevation contours and inferred groundwater flow directions should be considered an approximation for the semi-confined aquifer within the Plant and for the area southeast of the Plant, where control points are widely spaced or lacking.

Figure 3-15 indicates that the deeper, semi-confined aquifer within the Plant is recharged by the water-table aquifer in the northern part of the Plant, north of the northernmost extent of the recent silt and clay confining layer. It is also possible that the deeper aquifer receives some recharge from the water-table aquifer, which has leaked through the recent silt and clay semi-confining layer, because the vertical hydraulic gradient is downward in this area.

Inferred groundwater flow directions in the deeper, semi-confined aquifer within most of the Plant are to the south or southeast towards an apparent major groundwater discharge point in the vicinity of monitoring well MW-306. Inferred groundwater flow directions in the mapped portion of this aquifer within the Arsenal Business Center and Rohm & Haas facility are to the southwest or west, respectively, toward the same discharge point. Groundwater flow directions in the water-table aquifer located southeast of the Plant are also toward this discharge point in a generally northward direction.

The two most plausible explanations for the major groundwater discharge point near MW-306 are discharge to the Frankford Inlet or infiltration to the deep collector sewer line near this location. Tidal fluctuations in MW-306 (approximately  $\pm 0.1$  foot) versus those of the inlet (approximately  $\pm 6.0$  feet) indicate that the interconnection between the water-table aquifer and the inlet is rather limited at this location, possibly by the fine-grained sediments in the inlet. Tidal fluctuations in MW-301 (discussed in greater detail in Section 3.5.2.7) indicate that the deeper, semi-confined aquifer is poorly interconnected with the inlet and fluctuates more in response to tidal variations of the Delaware River. Water-level data indicate that gradients between the aquifer water levels and the inlet water levels at this location are only toward the inlet during periods of lower tides. No data are available to evaluate the extent of groundwater infiltration to the deep collector sewer line at this location, other than the fact that the line is sufficiently deep enough for this to occur.

The inferred groundwater flow direction in the deeper confined aquifer in the western part of the Plant is to the southwest and/or west toward an assumed groundwater discharge point located west of the Plant. Sufficient data are not available to form hypotheses regarding the location or mechanism for such a discharge point.

#### **3.5.2.6 Bedrock Unit**

No wells are completed within the saprolite and bedrock at the site; therefore, the site-specific characteristics and properties of this unit are unknown. The saprolite and bedrock are in direct contact with either the overlying sand and gravel deposits of the shallow water-table aquifer or those of the deeper, partially confined aquifer throughout most of the Plant. The exchange of groundwater between the bedrock unit and the overlying sedimentary aquifer is expected to be restricted by the low permeability residual clay of the saprolite layer wherever it is present. However, the residual clay saprolite layer is interpreted to be relatively thin at most places throughout the Plant. In smaller areas of the Plant where the saprolite and bedrock are directly overlain by the older silt and clay deposits (see Figure 3-11), groundwater movement between the bedrock and overlying sedimentary aquifer is expected to be more restricted. The actual degree of hydrogeologic interconnection between the bedrock unit and the overlying aquifer(s) at the site cannot be estimated from the available data.

#### **3.5.2.7 Aquifer Response to Tidal Fluctuations**

During the Phase II RFI, water levels in monitoring wells and piezometers were measured at frequent intervals throughout one or more tidal cycles to determine the aquifer response to tidal fluctuations in the Frankford Inlet and Delaware River. Water-level changes in the wells and piezometers were compared with tidal fluctuations recorded in the inlet at the Plant and from the nearby Delaware River to see if there was a discernible correlation between groundwater-level fluctuations and tidal fluctuations of the surface water bodies. The results of these investigations are summarized in Figure 3-16, and the data are included in Appendix F.

The results indicate that the shallow water-table aquifer is completely independent of surface water tidal fluctuations in the areas of the Plant north and west of the Frankford Inlet. Tidal fluctuations of the water table were observed in the more permeable, predominantly sand and gravel sediments and fill deposits located south and southwest of the inlet. The maximum observed tidally influenced water-table fluctuation was about  $\pm 0.46$  feet in monitoring well MW-109, located approximately 50 feet from the inlet, and decreased with increasing distance from the inlet. All of the observed tidal fluctuations in the water-table aquifer lagged behind those of the Frankford Inlet by approximately 15 to 180 minutes, depending upon the permeability of the aquifer materials and the distance from the inlet.

The observed tidally influenced water-table fluctuations were not great enough to change the pattern of groundwater elevation contours or the inferred groundwater flow directions shown in Figure 3-14. The observed tidal fluctuations would merely change the magnitude, not the direction, of the hydraulic gradient within the shallow aquifer adjacent to the Frankford Inlet to the south and southwest. The velocity of groundwater flow toward the inlet here will be slightly less during high tide because the hydraulic gradient is greatest during low tide conditions. The contours shown on Figure 3-14 represent conditions during low tide. The shallow aquifer north and west of the inlet is entirely uninfluenced by tidal fluctuations.

The deeper partially confined aquifer at the Plant showed tidally influenced fluctuations of the piezometric surface only in monitoring well MW-301 in the southeastern part of the facility. The farthest extent of tidal fluctuations in this aquifer is expected to occur somewhere between monitoring well MW-301 and monitoring wells MW-302 and MW-305, which exhibited no tidal influence. The observed tidally influenced fluctuation of the piezometric surface in monitoring well MW-301 was  $\pm 0.52$  feet. This fluctuation occurs approximately 30 to 50 minutes before that of the adjacent Frankford Inlet but 15 to 30 minutes after that of the Delaware River.

The timing of the tidal fluctuations in monitoring well MW-301 implies that the deeper, partially confined aquifer extends to, and is hydraulically interconnected with, the Delaware River. The data also suggest that any interconnection with the Frankford Inlet is indirect, through the shallow water-table aquifer. The tidal fluctuations in the deeper aquifer are not great enough to change the inferred groundwater flow direction shown in Figure 3-16, only the magnitude of the hydraulic gradient.

#### **3.5.2.8 Groundwater Infiltration to Existing Sewer Lines**

As mentioned previously in Sections 3.5.2.2 and 3.5.2.4, the coincidence of location between several apparent groundwater discharge points and the existing sanitary sewer lines suggests the likelihood of groundwater infiltration to the sewers. Measurements and observations were made in manholes and open weirs of the B, E, M, O, Wakeling Street, Frankford Inlet, and deep collector sewers to determine which portions of these sewers are subject to groundwater infiltration. These measurements and observations include the elevations of the top and invert of the sewer lines, the water surface elevation within the lines, photoionization detector readings or any recognizable odors emanating from within the manhole openings, visible evidence of contamination such as oily liquids, films, or sheens, and visual confirmation of the sewer construction and conditions. Analytical data from the B, E, M, O, and W sewer water, including phenol and various other chemical concentrations, were also evaluated. These chemical data are discussed in more detail in Section 4.3.



Figure 3-17 shows the approximate water-level elevations within the investigated sewer manholes. Whenever these elevations are less than the water-level elevation of nearby wells or the contoured water-level elevation of Figures 3-13 and 3-14, the sewer line is subject to the possibility of groundwater infiltration through any permeable openings. Such openings might result from cracked or broken, concrete, brick or vitrified clay, decomposed mortar, open or leaking pipe joints, corroded iron, or other types of structural failure. Figure 3-17 indicates that significant portions of the B, E, and M sewers and all of the Wakeling Street, Frankford Inlet, and deep collector sewers within the Plant are subject to the possibility of groundwater infiltration. The actual amounts or specific locations of groundwater infiltrating to sewer lines at the site cannot be determined with the available data.

Water levels in the B sewer are below the water table from a point near manhole B-2 in the southeastern corner of the parking lot all the way to the Frankford Inlet sewer. Groundwater elevation contours do not indicate any major discharge areas along this sewer line. Significant photoionization detector (PID) readings above background and slight chemical odors were observed only from manhole B-2. An LNAPL layer is present in nearby LNAPL well MW-207. No visible indication of infiltrating contaminated groundwater was evident in any of the B sewer manholes or weirs. Analytical data for phenol in water from sewer weir B-5 (presented in Section 4.3) suggest that some contaminated groundwater may be infiltrating to the B sewer. All of these data indicate that, while the B sewer may receive some groundwater infiltration, it is probably not a major avenue of groundwater discharge.

Water levels in the E sewer are below the water table from the area just southwest of monitoring well MW-209 all the way to the Frankford Inlet sewer. Groundwater elevation contours indicate that a major groundwater discharge point occurs near or along the E sewer line near well MW-201. Significant coal tar and naphthalene odors and above-background PID readings were noted in both manhole E-1 and open weir E-2. Oily substances coated some lower surfaces inside manhole E-1 and an oil sheen rose to the water surface when sediment near E-2 was disturbed. Corrosion holes were evident in the steel walls of weir E-2. Analytical data for phenol in water from sewer weir E-2 (presented in Section 4.3) indicate that there may be contaminated groundwater infiltration to the E sewer. All of these data indicate that groundwater infiltration and discharge may be occurring to the E sewer.

Water levels in the M sewer are below the water table from near manhole M-1 to the Deep Collector sewer line. Groundwater elevation contours indicate one major groundwater discharge point near the M sewer, but this is attributed to pumping in recovery well R-6, not sewer infiltration. Oily sheens and oil layers are occasionally observed atop the water in the M sewer and are most evident at the open weir M-3, where a belt stripper is in operation to remove oil. This oil could be due to infiltrating LNAPL, although M sewer also received process water. AlliedSignal recently implemented a project to repair portions of M sewer. The hydrogeological data do not indicate any major groundwater discharge points to the M sewer.

Water levels in the O sewer are above the water table except for the southern portion near manhole O-3. Groundwater elevation contours do not indicate any groundwater discharge areas along this sewer line. In fact, portions of this sewer line occur in an area of a consistent water-table highs. No significant odors, above-background PID readings, or visible signs of contamination were observed in any of the O sewer manholes. Allied data from the O sewer discharge point in November 1993 indicate that little if any infiltration of contaminated groundwater to O sewer is occurring, considering the groundwater contaminant levels near manhole O-3 (see Section 4.3). The hydrogeological data also do not indicate any major groundwater discharge points along the O sewer.

Water levels in the Wakeling Street sewer are below the water table along its entire length through the Plant. Groundwater elevation contours do not indicate any significant groundwater discharge areas along this sewer line. Cumene-like odors and above-background PID readings were obtained from all of the Wakeling Street sewer manholes but were greatest at the southernmost manhole W-3. No visible evidence of contamination or groundwater infiltration was observed during the Phase II RFI; however, LNAPL infiltration to this sewer was reportedly observed in the past. The data indicate that there may be some LNAPL or contaminated groundwater infiltration to this sewer line, but that it is probably not the recipient of any major groundwater discharge.

Water levels in the twin Frankford Inlet sewers are below the water table along its entire length through the Plant. Groundwater elevation contours indicate a major groundwater discharge point is located near piezometer P-118; however, this location also coincides closely with the location of the Deep Collector sewer line. Coal tar and/or naphthalene odors were noted from manholes only in the northernmost of the twin sewer lines. Oily sheens on water and an oily liquid on some surfaces were also noted only in the northern sewer line. No analytical data are available for the Frankford Inlet sewer lines.

In the western part of the Plant, the Frankford Inlet sewers appear to separate very contaminated groundwater to the north from relatively uncontaminated groundwater to the south (in wells MW-112 and MW-111) in spite of a mapped water-table hydraulic gradient to the south. This suggests that the sewer acts as a barrier to southward groundwater flow in this area either by intercepting the contaminated groundwater through infiltration or by completely blocking the flow and diverting it to the east and/or west. The available data indicate that the Frankford Inlet sewer is subject to some groundwater infiltration; however, it is not possible to determine the actual location or extent to which the infiltration occurs.

The deep collector sewer line is 10 to 15 feet or more below the elevation of the water table through the entire length within the Plant. A major groundwater discharge point is mapped near this line at piezometer P-118; however, it is uncertain whether this is related to the deep collector sewer line or to the Frankford Inlet sewer lines. Another major groundwater discharge point is mapped near the deep collector sewer line near monitoring wells MW-123 and MW-306. Measurements were only taken from one manhole near where the Frankford Inlet, Wakeling Street, and M sewer discharge to the deep collector sewer. The cumene odors noted at this location are probably from the M and Wakeling Street sewers. No analytical data are available for water from the deep collector sewer line. Hydrogeologic data indicate that groundwater infiltration to the deep collector sewer line may be a major avenue of groundwater discharge at two separate locations; however, this cannot be confirmed with the available data.

Many abandoned sewer lines for which no manholes currently exist are also located within the Plant. Several of these are located in the southwestern part of the Plant and formerly discharged to the Frankford Inlet sewer. Depending upon the type of abandonment procedures used, these sewers may also be prone to groundwater infiltration if they occur at elevations below the water table.

No manhole or water level measurements were made for W sewer (see Figure 2-3). Therefore, its susceptibility to infiltration can not be evaluated completely. However, an apparent groundwater discharge area in the vicinity of piezometer P-120 (see Figure 3-14) suggests that W sewer and/or the sewer line beneath former Granite and Milnor Streets may be subject to groundwater infiltration. No field observation or measurements are available for the Granite and Milnor Streets sewer line; however, City of Philadelphia Water Department maps indicate that the line may occur at an elevation low enough to allow groundwater infiltration. AlliedSignal W sewer analytical data indicate that some contaminated groundwater may be infiltrating to this sewer line (see Section 4.3); however, this infiltration is probably not significant.

### **3.6 POTABLE WATER SUPPLY AND LOCAL GROUNDWATER USE**

Residents within the City of Philadelphia surrounding the Plant obtain drinking water from the Philadelphia Water Department (PWD). PWD obtains water from two intakes on the Schuylkill River and one intake on the Delaware River. The PWD Torresdale intake is located in the tidally influenced portion of the Delaware River at river mile 110.5, approximately 5.5 miles upstream of the mouth of the Frankford Inlet. No surface water intakes used for drinking water supplies have been identified downstream of the Plant (NUS, 1989, and NUS, 1991).

Groundwater is used as a source of drinking water in New Jersey on the opposite side of the Delaware River. The Camden City Water Department (CCWD) maintains several municipal supply wells in the area approximately 1.4 miles or more southeast of the Plant. The New Jersey Water Company (NJWC) supplies water in the Palmyra area and also uses wells for drinking water supply. Both CCWD wells and NJWC wells produce from the Magothy Raritan aquifer system (Weston, 1980; NUS, 1989; and NUS, 1991).

Records are available for approximately 54 wells that have been installed on the Pennsylvania side of the Delaware River within about one mile of the Plant (Paulachok, et al., 1984, Greenman, et al., 1961). Approximately 40 percent of these wells were reportedly completed in schist or gneiss bedrock and another 40 percent were reportedly completed in Pleistocene sand and gravel deposits. The remaining 20 percent were reportedly completed in the lower sand unit of the Potomac - Raritan - Magothy aquifer system. In this area of the Pennsylvania Coastal Plain, the lower sand unit of the Potomac - Raritan - Magothy aquifer system is equivalent to the Farrington sand member of the Raritan Formation (Greenman, et al., 1961 and Paulachok, et al., 1984). Of the 54 wells, one was reportedly used for industrial water supply withdrawals, 14 were reportedly used as observation wells, and the rest were reported to be either unused or destroyed (Paulachok, et al., 1984, and Greenman, et al., 1961).

Of the 54 wells identified in the records, 18 are (or were) on the Rohm & Haas Delaware Valley, Incorporated property and five were on the Plant property. The Plant now relies entirely upon the PWD for its supplies. The five former supply wells at the Plant have been destroyed; however, the abandonment dates and procedures are not known. Four of the Rohm & Haas wells were supply wells that were reportedly destroyed. The remaining 14 Rohm and Haas wells listed in the records are groundwater monitoring wells. The Rohm & Haas, Delaware Valley facility currently has no groundwater withdrawals (Palena, 1993).

The Arsenal Business Center, located directly east of the Plant, is supplied by the PWD, but the Center did have at least five monitoring wells on the property at one time (NUS, 1989).

Attempts were made during the Phase II RFI to verify the current status of the wells listed in the available records. Verification procedures included field reconnaissance and door-to-door inquiries at the reported well locations, telephone inquiries to the owners, occupants, or neighbors of the reported well locations, and interviews with long-time residents and/or employees of the area surrounding the Plant. These attempts were successful for approximately 85 to 90 percent of the listed wells. Those wells not verified are reported as destroyed in the available records.

All the persons contacted at the reported well locations verified that they do not presently use groundwater and they have not used it within recent years. Several of the reported wells have definitely been destroyed or are presumed to have been destroyed based upon the current use or appearance of the reported location. Most of the facilities reported to have once used groundwater are now either unoccupied or are occupied by different tenants or owners who receive water from the PWD. Based on the recollections of the interviewees considered to be most knowledgeable of local drinking water sources, there has been no significant groundwater use in the area for 10 to 20 years or more. In no instances did any of the individuals interviewed provide information on the abandonment procedures or current status of the unused or destroyed wells. Based on the above, B&R Environmental does not believe there are any groundwater users within one mile of the Plant.

### **3.7 POPULATION AND LAND USE**

The Plant lies in the Bridesburg section of Philadelphia, Pennsylvania. Immediately adjoining the Plant to the south is a densely populated residential area. A mixed residential and industrial area lies across Interstate 95 north of the facility. The TIP Trailer sales lot (F.P. Woll property) is located immediately west of the Plant. The Arsenal Business Center is located east of the Plant and consists of professional offices and warehouses (NUS, 1989). The Rohm and Haas Delaware Valley, Incorporated Philadelphia chemical plant is located southeast of the Plant. No schools, day care facilities, senior citizens centers, or hospitals abut the Plant.

### **3.8 ECOLOGY**

The site is an urban industrial area with restricted access that supports very little vegetation. The only ecological receptors identified are aquatic species in the Frankford Inlet and the Delaware River.

The shortnose sturgeon (Acipenser brevirostrum) can be found in the Delaware River. This fish is listed by the Pennsylvania Fish Commission and the United States Fish and Wildlife Service as endangered (Shiffer, 1983). As stated in the Plant Part B Permit Application (Allied, 1985), the site was not categorized as located in the corridor of a stream or a river designated as a national, or state wild, scenic, recreational, or modified recreational river in accordance with the National Wild and Scenic Rivers Act of 1968 or the Pennsylvania Scenic Rivers Act. Based on the available information, the site is not located within one mile of a 1A priority for study stream or river under PADER's determination of a state wild, scenic, recreational, or modified recreational river (Allied, 1985).

A report has been prepared by the Delaware River Basin Commission (DRB) based on a fish population study done by the Pennsylvania Fish Commission during the summers of 1984 to 1986 on Zones 2, 3, and 4 of the Delaware River. The Plant surface waters of concern fall within Zone 3. Thirty-six fish species were reported in Zone 3, and 53 species were reported for all three zones. Among the Zone 3 species were blueback herring, white perch, silvery minnow, spottail shiner, banded killifish, pumpkinseed sunfish, inland silverside, alewife, mummichog, and channel catfish (DRBC, 1987). A subsequent health and contamination study was conducted on the catfish family and white perch. It was concluded that the fish were generally healthy, and observed pathologic conditions could not be correlated to toxicants in the river. The fish were reportedly affected by some physical stresses such as seasonal high water temperature and the onset of spawning. Accumulation of PCBs, DDT metabolites (below Food and Drug Administration Action Levels), and chlordane was reported. Accumulation of some metals, such as arsenic, was also reported. Mainly because of the PCBs, the study concluded that the edibility of some fish species could be questionable (DRBC, 1988).

## **4.0 NATURE AND EXTENT OF CONTAMINATION**

This section presents a summary of the nature and extent of contamination detected in soil and groundwater samples. This presentation will focus on analytical results from the Phase II RFI, as well as results from the Phase I investigation and the previous LNAPL investigations. In addition, available data on potential groundwater infiltration into sewer lines is summarized, and the results of the most recent sampling of Plant drinking water lines are presented.

### **4.1 ON SITE SOILS/FILL MATERIAL DATA**

The Phase I RFI was designed to evaluate the nature and extent of vadose zone soil/fill contamination. The Phase II RFI focused more on the nature and extent of groundwater contamination while supplementing the soil/fill contamination data base. For details of the findings of the Phase I investigation, see Sections 4.0 through 7.0 of the Phase I RFI report (Halliburton NUS, May 1992). The major findings are summarized in the following section.

#### **4.1.1 Summary of Previous Investigations**

The Phase I investigation included the drilling of 60 soil borings throughout the site. A vadose zone soil/fill sample for chemical analysis was collected from 37 of the borings. Also, selected samples were submitted for grain size distribution analysis. Chemical analyses included TCL VOC, TCL BNA, AMS, cumene, and TOC. The occurrence and distribution of chemicals detected in these samples are summarized in Table 4-1. Figures 4-1, 4-2, 4-3, and 4-4 summarize the findings for six primary Plant contaminants and contaminant classes [benzene, cumene, AMS, phenol, naphthalene, and polycyclic aromatic hydrocarbons (PAHs)].

The soil boring data also indicated that LNAPL-containing soils are present in a 17-acre area within the Plant boundaries (see Section 4.2.1).

The Phase I RFI concluded that, because vadose zone soil/fill contamination is relatively continuous throughout the facility, the area of contamination beneath the Plant should be considered as one study area similar to a Corrective Action Management Unit (CAMU) for any further RCRA corrective action activities.

**TABLE 4-1**  
**OCCURRENCE AND DISTRIBUTION OF ORGANIC COMPOUNDS IN**  
**PHASE I SOIL/FILL SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/kg)**

Chemical	Frequency of Positive Detections	Range of Positive Detections
1,2-Dichloroethene	1/37	0.02
Acetone	1/37	41
Alpha-methyl styrene	14/37	0.0075 to 700
Cumene	26/37	0.005 to 2,000
Trichloroethene	1/37	0.01
4-Methyl-2-pentanone	1/37	1.8
Styrene	8/37	0.88 to 320
Chlorobenzene	1/37	2.0
Benzene	11/37	0.012 to 42
Toluene	15/37	0.004 to 200
Ethylbenzene	16/37	0.0075 to 130
Xylenes	20/37	0.011 to 940
Benzoic Acid	1/37	32
Phenol	13/37	0.34-450
2-Methylphenol	6/37	0.42 to 390
4-Methylphenol	10/37	0.65 to 1,300
2,4-Dimethylphenol	12/37	0.15 to 5,000
PAHs (minus naphthalene)	25/37	0.34 to 43,000
Naphthalene	28/37	0.15 to 690,000
Phthalates	15/37	0.48 to 270
Carbon disulfide	1/37	0.015
N-Nitrosodiphenylamine	1/37	0.31

(Duplicate samples were averaged using 1/2 detection limit for non-detections)



Five additional shallow soil borings (see Figure 4-6) were drilled along Lefevre Street and on the adjacent F.P. Woll property after the discovery of the naphthalenic crystalline material in the MW-122 boring (i.e., sample S0-122-13). Split-spoon soil sampling was performed in order to visually identify the extent of the crystalline material. Three borings (SB-63, SB-64, and SB-65) (two north of MW-122 and one south of MW-122) were located on a line with MW-122 parallel to the north-south direction of Lefevre Street. The fourth boring (SB-66) was located approximately 50 feet southwest of MW-122, and the fifth boring (SB-67) was located approximately 75 feet northwest of MW-122.

Soil boring SB-65, located approximately 50 feet north of MW-122, encountered a few inches of brown crystalline material with a naphthalenic odor between three and four feet below the surface. Soil boring SB-66 encountered a few inches of brown crystalline material with a naphthalenic odor in a layer between six and seven feet below the surface. The remaining soil borings did not encounter crystalline material.

Based on these findings, 29 additional soil borings were installed with the Geoprobe soil boring system (see Figure 4-6). Geoprobe borings were drilled along Lefevre (Margaret) Street and on the adjacent F.P. Woll property to further delineate the extent of naphthalenic crystalline material.

Two borings (SB-A and SB-B) were installed inside the Plant boundary near the prior naphthalenic crystalline material discovery, and seven soil borings (SB-C, SB-CD, SB-D, SB-E, SB-EF, SB-F, and SB-FG) were drilled along the Plant boundary. Three of these seven borings (SB-D, SB-E, and SB-EF) and one boring within the Plant (SB-A) encountered naphthalenic crystalline material (see Figure 4-6). Soil borings SB-A and SB-D encountered a layer of naphthalenic crystals in the subsurface approximately two feet below the ground surface. Soil boring SB-E, 50 feet south of SB-D, encountered a layer of naphthalenic crystals approximately four feet below the surface. Naphthalenic crystals were found in soil boring SB-EF, located about 25 feet south of SB-E, at a depth of 10 to 12 feet below the surface. The remaining borings were installed to better delineate the horizontal extent of the crystalline material. Boring results are presented on Figure 4-6.

The naphthalenic crystals appear at two depths, one relatively shallow and the other deeper near the bottom of the fill deposits. The shallow crystalline material is found in two zones. One zone is found in soil borings SB-A, SB-K, SB-D, SB-E, and SB-65, and the second zone is in soil borings SB-LM, SB-M, SB-66, and MW-122. The deeper occurrence of naphthalenic crystals appears in soil borings SB-L, SB-LM, MW-122, SB-Q, SB-R, SB-S, SB-Y, SB-Z, and SB-CB. Cross-sections of the area are provided in Figures 4-7 and 4-8.

The horizontal extent of naphthalenic crystals has been determined on the northern and western sides by soil borings SB-C, SB-CD, SB-3, SB-JK, SB-P, SB-6, SB-V, SB-W, SB-EE, SB-FF, and SB-GG, which did not encounter naphthalenic crystals.

The eastern boundary of the naphthalenic crystals is partially defined by the following soil borings absent of naphthalenic crystals: SB-FG, SB-MN, SB-1, SB-LE20, SB-39, SB-42, SB-44, DB-3, and MW-119. (Note: Soil borings SB-37, SB-38, and SB-43 shown on Figures 1, 2, and 3 were not drilled deep enough to conclusively confirm the absence of deep naphthalenic crystals to these points). Borings SB-53, SB-56, SB-27, MW-103, SB-52, MW-117, and MW-111 were installed (previously) east of the SB-CB location. No crystalline material was encountered in these borings, suggesting the crystalline material does not extend as far east as these borings. However, not all of these borings were continuously sampled, and only two of these borings (SB-56 and MW-111) extended to the deepest interval that naphthalenic crystals were observed in boring SB-CB (i.e., immediately above the silt-clay layer).

Boring MW-112 was (previously) drilled south of the SB-CB location. No crystalline material was encountered in this boring, which was extended to a depth of 16 feet.

Naphthalenic crystals were traced as far south as boring SB-Z. Borings could not be advanced to the south of this location, because utility clearances had not been obtained. Additionally, AlliedSignal did not have an access agreement with the owner of the property to the south of the F.P. Woll property. (Also, a boring could not be advanced east of the SB-Z location on the F.P. Woll property, because immobile trailers were situated there. In its place, boring SB-CB was installed in the southwestern corner of the Plant).

## **4.2 GROUNDWATER DATA**

The Phase I investigation was primarily focused on the extent of soil contamination, but three shallow wells were installed and limited groundwater sampling occurred. The limited analytical data from the Phase I groundwater investigation indicated the need for determination of the extent of shallow groundwater contamination. Thus, the Phase II investigation focused on the horizontal and vertical extent of groundwater contamination.

#### **4.2.1 Previous Investigations**

Prior to initiation of the Phase I RFI, AlliedSignal collected and analyzed samples from groundwater recovery wells R2, R3, R5, and R6 in September 1990 and samples from recovery wells R5 and R6 (see Figure 2-1) in October 1990. The September 1990 sample results are presented in Table 4-2. Results from the October 1990 samples, which are similar to the September 1990 sample results, were presented in the Phase I RFI report (Halliburton NUS, May 1992).

Phase I results from samples from the three Phase I monitoring wells (MW-101, 102, and 103) are presented in Table 4-3. No LNAPL was noted in these wells at the time of sample collection.

LNAPL-containing soils were discovered beneath approximately 17 acres of the Plant during the Phase I RFI (Halliburton NUS, May 1992). To further assess the LNAPL and the possibilities for recovery, additional studies were performed. As a part of the test work, 10 LNAPL wells (MW-201 through MW-210) were installed. Free-phase LNAPL was noted (in December 1992) in wells MW-202, MW-203, MW-205, MW-207, MW-208, and MW-210, and free-phase DNAPL was noted in well MW-201. The extent of LNAPL-containing soils and free-phase LNAPL in December 1992 is portrayed on Figure 4-9. In March 1993, laboratory analyses of free-phase product samples collected from wells MW-201, MW-202, MW-205, MW-207, and MW-208 were performed. The analytical results are presented in Table 4-4. The analytical results indicate that the free-phase product at the Plant consists of a complex mixture of compounds, with significant variation in actual chemical composition between various sample locations. Cumene (isopropylbenzene) concentrations in the samples range from non-detected (the 20 compounds at the greatest concentrations were identified in the GC analysis) to a concentration of 44 percent. Cumene was not identified in the samples analyzed from wells MW-201 (DNAPL location) and MW-207 (only coal-tar-related chemicals were identified). Samples from MW-202 and MW-205 contained primarily cumene-process-related chemicals (cumene, alpha-methylstyrene, and acetophenone), whereas the sample from well MW-208 contained more than 30 percent of coal-tar-related chemicals (including more than 12 percent phthalates) and more than 20 percent of cumene-related chemicals. The results indicate that three types of compounds are present in the LNAPL layer in the area of well MW-208.

**TABLE 4-2**  
**SEPTEMBER 28, 1990 RECOVERY WELL ANALYTICAL DATA**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/l)**

CHEMICAL	R2	R3	R5	R6
Methylene chloride	ND	ND	3.6 L	ND
Acetone	2.3 B	7.3 B	52 L	32 L
2-Butanone	ND	ND	1.4 L	ND
Benzene	ND	1.6 L	6.5	36 L
Toluene	ND	0.74 L	1.6 L	14 L
Ethylbenzene	ND	ND	0.55 L	1.2 L
Styrene	ND	ND	ND	0.68 L
Xylenes	ND	ND	0.87 L	5.3 L
2-Methylphenol	0.14 L	5.3 L	ND	0.57 L
4-Methylphenol	0.39 L	19 L	ND	1.7 L
Pyridine	0.031 L	0.51 L	ND	ND
2,4,5-T	ND	ND	0.0017	0.0006 J
Arsenic	0.080	0.371	0.013	ND
Barium	0.121	0.024	0.110	0.178
Cadmium	ND	ND	0.0002	ND
Chromium	0.103	0.023	0.007	0.650
Lead	0.002	0.149	0.063	0.063
Mercury	ND	0.072	ND	ND

B = Attributed to blank contamination  
 L = Biased low  
 ND = Not detected  
 J = Estimated

**TABLE 4-3**  
**PHASE I MONITORING WELL RESULTS - ORGANIC COMPOUNDS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/l)**

CHEMICAL	MW-101	MW-102	MW-103*
Acetone	ND	ND	150 J
Benzene	ND	ND	57 J
Toluene	ND	ND	22.5 J
Chlorobenzene	ND	ND	0.86 J
Styrene	ND	ND	0.58 J
Xylenes	ND	ND	1.6
Cumene	0.26	0.004 B	< 1
Phenol	ND	ND	59
2-Methylphenol	ND	ND	2
4-Methylphenol	ND	ND	3.6
2,4-Dimethylphenol	ND	ND	4.7
Benzoic acid	ND	ND	9.7 J
Naphthalene	0.033	ND	18
2-Methylnaphthalene	ND	ND	1.5
Acenaphthalene	0.013	ND	ND
Dibenzofuran	0.007 J	ND	ND

\* Results were the arithmetic mean of duplicates, using 1/2 of the detection limit for non-detects.

ND = Not detected  
B = Attributed to blank contamination  
J = Estimated

**TABLE 4-4**  
**FREE-PHASE PRODUCT SAMPLE RESULTS**  
**MARCH 25, 1993 SAMPLING EVENT**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

*(All Data in Percent Unless Otherwise Indicated)*

	MW-201 (DNAPL)	MW-202 (LNAPL)	MW-205 (LNAPL)	MW-207 (LNAPL)	MW-208 (LNAPL)
Cumene	---	41	44	---	23
Alpha-methylstyrene	---	9.9	---	0.96	2.8
1,1'-(1,1,2,2-Tetramethyl- 1,2-ethanediyl)bis-benzene	---	0.96	---	---	---
1,1'-(1,2-Ethynediyl)- bis-benzene	1.7	---	---	---	---
Acetophenone	---	---	0.85	---	---
Toluene	1.2	---	---	3.1	3.8
Ethylbenzene	---	---	---	1.8	0.91
o-Xylene	1.5	---	---	7.4	4.2
m-Xylene	---	---	---	---	2.1
p-Xylene	2.1	---	---	3.7	---
1-Methylethylbenzene	---	---	---	1.0	---
1,3,5-Trimethylbenzene	0.72	---	---	1.2	---
Alkylbenzene	2.1	---	---	2.7	---
1,2,4-Trimethylbenzene	0.69	---	---	0.76	---
1-Ethyl-3-methyl-benzene	---	---	---	---	0.57
1-Ethenyl-2-methyl-benzene	---	---	---	1.4	---
9H-Fluorene	1.4	---	---	---	---
1H-Indene	4.5	---	---	2.3	0.96
2,3-Dihydro-1H-indene	1.8	---	---	---	---
1-Ethylidene-1H-indene	9.1	---	---	1.2	---
Naphthalene	12	---	---	4.8	5.2
1-Methylnaphthalene	4.9	---	---	0.56	3.8
1,3-Dimethylnaphthalene	2.2	---	---	---	---
1,5-Dimethylnaphthalene	1.5	---	---	0.56	3.8

**TABLE 4-4**  
**FREE-PHASE PRODUCT SAMPLING RESULTS**  
**MARCH 25, 1993 SAMPLING EVENT**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE TWO OF TWO**

	MW-201 (DNAPL)	MW-202 (LNAPL)	MW-205 (LNAPL)	MW-207 (LNAPL)	MW-208 (LNAPL)
Diisooctyl phthalate	---	---	---	1.2	9.7
Bis(2-methoxyethyl) phthalate	---	---	---	---	1.8
Butyl cyclohexyl phthalate	---	---	---	---	0.9
Dibenzofuran	2.6	---	---	---	---
Benzo(b)thiophene	0.93	---	---	---	0.52
Acenaphthene	2.6	---	---	---	---
Quinoline	---	---	---	---	1.6
Isoquinoline	---	---	---	---	0.55
1,1-Biphenyl	2.4	---	---	---	---
4-(1-Methyl-1-phenylethyl)- phenol	---	0.56	---	---	---
Specific Gravity (unitless)	1.019	0.877	0.915	0.951	0.929

Note: Only compounds with measured concentrations greater than 0.5 percent are shown. All data are provided in Appendix A.

## **4.2.2 Phase II Groundwater Investigation**

### **4.2.2.1 Shallow Groundwater**

During Stage I of the Phase II RFI, a network of 20 piezometers was installed to more clearly define the groundwater flow patterns beneath the site (see Section 3.4.2). Qualitative headspace screening of samples from these piezometers for volatile organic compounds was performed utilizing a portable field photoionization detector (HNu meter). Results from this screening exercise are portrayed on Figure 4-10. The headspace screening data indicated probable volatile organic contamination west of the Plant along Lefevre (Margaret) Street. Very low (< 1 ppm) volatile detections were noted along the southern and eastern property boundaries. It should be noted that the HNu meter used does not distinguish among compounds and is subject to interferences (e.g., from natural organic material). The headspace screening results conform with EPA Data Quality Objective (DQO) Level 1 (EPA, 1987) and are considered to be qualitative.

Based on these preliminary headspace results and the updated shallow groundwater flow model, groundwater samples were collected from 23 temporary drive point probes for on-site analysis in a mobile laboratory (i.e., rapid turnaround analysis) during Stage II. The analytical methodology used is described in Section 2.2.2.1. The six sample analytes were benzene, chlorobenzene, ethylbenzene, toluene, total xylenes, and cumene. Sample results are provided in Figure 4-11. The sample results provided a preliminary indication of the horizontal extent of shallow groundwater contamination. Except for an area along Lefevre (Margaret) Street, shallow groundwater contamination appeared not to extend beyond the Plant boundary. Samples from the three locations along Lefevre Street (LE-20 to LE-22) contained benzene at 0.005 to 0.075 mg/l, toluene at 0.015 to 0.15 mg/l, ethylbenzene at 0.049 to 0.27 mg/l, total xylenes at 0.160 to 1.0 mg/l, and cumene at 0.017 to 0.18 mg/l. The rapid turnaround groundwater sample results conform with EPA DQO Level II (EPA, 1987). Details on the rapid turnaround program are contained in Appendix G.

The horizontal extent of contamination to the west of Lefevre Street could not be determined during the real-time groundwater sampling program because AlliedSignal did not then have access (or utility clearances) to the adjacent privately owned lot (F.P. Woll property). The extent of shallow groundwater contamination was later determined during the well installation, sampling, and analytical phase of the investigation (Stage III), which occurred after access to the F.P. Woll property was obtained.



Twenty-five shallow groundwater samples were collected during Stage III of the Phase II RFI. Sample locations included the three wells installed during the Phase I RFI (MW-101, MW-102, and MW-103), MW-204, which was installed during the free-phase product conceptual design study, a groundwater seep along the north bank of the Frankford Inlet, and the 20 shallow wells installed during the Phase II RFI.

Tables 4-5 and 4-6 present a summary of the occurrence and distribution of organic chemicals and of metals and engineering parameters, respectively, detected in the Phase II RFI shallow groundwater samples. Organic chemicals detected are presented on Plate 1. The analytical results conform with EPA DQO Level IV (EPA, 1987) and should be considered much more reliable than the headspace screening and rapid turnaround sampling results.

The most significant conclusion that can be drawn from the Phase II RFI shallow groundwater sample results is that the extent of shallow groundwater contamination appears to be delineated. Fourteen shallow groundwater monitoring wells (MW-108, MW-102, MW-118, MW-110, MW-121, MW-120, MW-112, MW-114, MW-115, MW-116, MW-123, MW-104, MW-105, and MW-106) placed around the perimeter of the site were sampled. Only the sample results from monitoring well MW-110 indicated significant groundwater contamination. The compounds detected in other perimeter wells were all detected at relatively low concentrations (i.e., less than 0.05 mg/l). Of the five compounds detected in perimeter wells [chloroform, toluene, bis(2-ethylhexyl) phthalate, cumene, and 1,1,1-trichloroethane], two of the compounds [toluene, and bis(2-ethylhexyl) phthalate] are common laboratory contaminants. The compound 1,1,1-trichloroethane was detected only in the sample from monitoring well MW-108 at the northernmost edge of the Plant. This compound's presence could be attributable to an off-site, upgradient source. Chlorinated compounds were not commonly used at the Plant and have not typically been detected in previous sampling effects.

Inside the Plant, benzene, toluene, xylenes, and/or ethylbenzene were detected at concentrations above 1 mg/l in samples from monitoring wells MW-204, MW-119, MW-103, MW-117, and MW-110. All of these wells are located in the western half of the site. As can be seen in Plate 1, the detected compound concentrations decrease from east to west. The highest concentrations of benzene (160 mg/l and 120 mg/l, duplicate) and toluene (43 mg/l) were found in the samples from monitoring wells MW-117 and MW-103, respectively, located in the former Frankford Creek bed. The benzene and toluene results are approximately eight percent of the compounds' reported solubilities at 25°C. The MW-117 sample result corresponds to the soil/fill sample SO-117-10 result, which indicated benzene and toluene levels of 16,000 mg/kg and 14,000 mg/kg, respectively, at a 10-foot depth at the same location. The soil/fill sample was collected from a depth within the screened interval of the monitoring well. The next highest benzene concentration (72 mg/l) was measured in the sample from monitoring well MW-103. During the sampling of monitoring well MW-103, significant oily and tarry residue clung to the sampling equipment. Small black to dark brown oily droplets were present in the sample. These droplets settled to the bottom of the container a few minutes after sampling, indicating the presence of DNAPL at this location.

**TABLE 4-5**  
**OCCURRENCE AND DISTRIBUTION OF ORGANIC CHEMICALS IN PHASE II**  
**SHALLOW GROUNDWATER SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/l)**

CHEMICAL	FREQUENCY OF POSITIVE DETECTIONS	RANGE OF POSITIVE DETECTIONS
Acetone	1/25	885
2-Butanone	2/25	0.012 to 0.053
Total-1,2-Dichloroethene	1/25	0.005
Chloroform	2/25	0.020 to 0.037
1,1,1-Trichloroethane	1/25	0.004
Benzene	9/25	0.039 to 140
2-Hexanone	1/25	0.013
4-Methyl-2-pentanone	1/25	0.006
Toluene	8/25	0.012 to 43
Ethylbenzene	6/25	0.010 to 2.6
Styrene	2/25	0.021 to 0.530
Total xylenes	8/25	0.090 to 21
Phenol	8/25	0.054 to 445
2-Methylphenol	6/25	0.16 to 22
4-Methylphenol	7/25	0.41 to 78
Hexachloroethane	1/25	0.048
2,4-Dimethylphenol	7/25	0.64 to 87
Naphthalene	10/25	0.003 to 43
2-Methylnaphthalene	6/25	0.061 to 3.4
Acenaphthene	6/25	0.028 to 0.330
Dibenzofuran	7/25	0.025 to 0.310
Fluorene	5/25	0.021 to 0.210
Phenanthrene	4/25	0.026 to 0.190
Anthracene	1/25	0.011
Carbazole	1/25	0.071
Cumene	9/25	0.007 to 0.72
Bis(2-ethylhexyl) phthalate	1/25	0.005

**TABLE 4-6**  
**OCCURRENCE AND DISTRIBUTION OF METALS AND OTHER MISCELLANEOUS PARAMETERS**  
**DETECTED IN PHASE II SHALLOW GROUNDWATER SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(all data in mg/l)**

CHEMICAL	FREQUENCY OF POSITIVE DETECTIONS	RANGE OF POSITIVE DETECTION (mg/l)
Aluminum	4/25	0.206 to 25.3
Arsenic	14/25	0.0021 to 0.517
Barium	24/25	0.003 to 0.353
Cadmium	1/25	0.080
Calcium	25/25	6.39 to 340
Chromium	9/25	0.012 to 1.09
Iron	20/25	0.043 to 129
Lead	1/25	0.052
Magnesium	25/25	1.89 to 61.78
Manganese	25/25	0.042 to 19.9
Nickel	12/25	0.021 to 3.41
Potassium	25/25	1.46 to 47.9
Selenium	4/25	0.0012 to 0.18
Sodium	25/25	4.96 to 1,600
Vanadium	6/25	0.009 to 0.085*
Zinc	7/25	0.009 to 0.738
Total organic carbon	25/25	1 to 3,100
BOD <sub>5</sub>	17/25	1 to 4,700
Total Hardness (as CaCO <sub>3</sub> )	25/25	20 to 1,100
Total Alkalinity (as CaCO <sub>3</sub> )	25/25	17 to 2,700
Dissolved Solids (180°C)	25/25	110 to 4,400

\* The result is the arithmetic mean of two duplicates.

The presence of acetone was only positively confirmed in one shallow groundwater sample, from monitoring well MW-117. Acetone was also detected at an elevated concentration in the sample from monitoring well MW-103, but this result is considered unusable because acetone was also detected in the associated laboratory blank. (Acetone was detected in the Phase I RFI sample from monitoring well MW-103 at a concentration of 150 mg/l.)

Monitoring wells MW-103 and MW-117 are located approximately 200 feet south of the acetone tank car loading area and the former benzene-toluene-xylene refinery, respectively. The presence of the BTEX compounds and acetone in the samples from these wells is probably related to the wells' geographical setting. Based on the existing water-level data, shallow groundwater in the vicinity of monitoring well MW-117 probably infiltrates into one of the city sewers running along the former Frankford Creek bed, whereas shallow groundwater in the vicinity of monitoring well MW-103 probably infiltrates into either these sewers or the E sewer (see Section 3.5).

The highest levels of ethylbenzene (2.6 mg/l) and total xylenes (21 mg/l) detected in shallow groundwater samples during the Phase II RFI were detected in the sample from monitoring well MW-204. This xylene result is 11 percent of the reported xylene solubility. Free-product analyses conducted during the LNAPL pilot testing indicated that total xylenes make up 3.6 percent of the DNAPL sampled from monitoring well MW-201 (located approximately 120 feet south of MW-204) and 11.1 percent of the LNAPL sampled from monitoring well MW-207 (located approximately 230 feet north of MW-204). Ethylbenzene was also detected in the LNAPL sample from monitoring well MW-207 at a concentration of 1.8 percent but was not detected in the sample from monitoring well MW-201 (see Table 4-4). As described in Section 3.5, groundwater in the vicinity of monitoring well MW-204 probably infiltrates into the E sewer.

Phenol was detected at concentrations greater than 1 mg/l in samples from monitoring wells MW-101, MW-117, MW-204, MW-119, MW-103, and MW-117. The highest levels of phenol (400 mg/l and 490 mg/l) were detected in the duplicate samples from monitoring well MW-117, with the next highest level (210 mg/l) detected in the sample from monitoring well MW-103. Phenol was detected at 50 mg/l in the Phase I RFI sample from MW-103. No nearby source areas for these phenol detections have been identified.

A phenol concentration of 9.4 mg/l was measured in the Phase II RFI sample from monitoring well MW-101. No phenol was detected in the Phase I RFI sample from this well.

An elevated level of phenol (53 mg/l) was also detected in the sample from monitoring well MW-107. The two highest phenol soil concentrations measured during the Phase I RFI came from soil samples collected from soil borings 41 and 51 (see Figure 4-3). These borings were located immediately to the northwest of monitoring well MW-107.

Cresols (2-methylphenol and 4-methylphenol) and the related 2,4-dimethylphenol were measured at concentrations exceeding 1 mg/l in samples from monitoring wells MW-110, MW-119, MW-204, MW-103, MW-117, and MW-107, with the highest concentrations being measured in the sample from monitoring well MW-107. The 2,4-dimethylphenol concentration of 87 mg/l reported for the monitoring well MW-107 sample is 15 percent of the compound's reported solubility at 25°C (see Section 5.0). Concentrations of 200 mg/kg and 5,000 mg/kg of 4-methylphenol and 2,4-dimethylphenol, respectively, were detected in the sample from nearby soil boring SB-51 collected during the Phase I RFI (Halliburton NUS, May 1992). This sample was taken from fill material likely used to backfill the former Frankford Creek meander. Groundwater in the vicinity of monitoring well MW-107 is believed to seep into the Frankford Inlet, albeit at an exceedingly slow rate (see Section 3.5).

Naphthalene and other PAH compounds were detected at concentrations greater than 1 mg/l in the samples from monitoring wells MW-122, MW-119, MW-204, MW-107, MW-103, and MW-117. In all of these samples, the reported naphthalenic concentration exceeded 10 percent of its reported solubility of 31 mg/l at 25°C. In the case of the sample from monitoring well MW-122, the analytical result exceeds the compound's reported solubility. Monitoring well MW-122 is partially screened across the interval where crystalline naphthalenic materials were reported. The elevated groundwater result could be due to suspended naphthalenic solids present in the groundwater sample.

Monitoring well MW-107 is located just south of soil borings SB-33 and SB-41. Naphthalenic crystalline materials containing up to 69 percent naphthalene were encountered in these borings (see Figure 4-4) (Halliburton NUS, May 1992). This material probably contributed to the elevated naphthalenic concentration (19 mg/l) detected in the sample from monitoring well MW-107.

Although cumene was detected in monitoring wells MW-119, MW-204, MW-113, MW-101, and MW-107, MW-110, and MW-122, no detected concentrations exceeded 1 mg/l. The two highest cumene levels of 0.72 mg/l and 0.12 mg/l were detected in the samples from monitoring wells MW-204 and MW-110, respectively. Alpha-methylstyrene was not detected in the Phase II shallow groundwater samples.

Dissolved metal analytical results are included in Table 4-6. Although analytical results from filtered groundwater samples reveal some positive detections of various inorganic contaminants, widespread metals contamination was not noted at the site. Most of the detections are isolated to a few samples and show little consistency across the site. Chromium was detected in nine of 25 groundwater samples. The only groundwater sample containing chromium at a level greater than 1 mg/l was from MW-103 (1.09 mg/l). Metal concentrations in general are higher in samples from wells MW-103, MW-107, and MW-117. Other metals detected in one or more of the groundwater samples from these wells include cadmium, lead, nickel, and arsenic. The metals detected in the groundwater samples could possibly be attributable to the materials used to fill the creek bed, possibly including incinerator ash from the City of Philadelphia (NUS, 1989).

Comparison of the analytical data of the Phase I groundwater samples (February 1992) (see Table 4-3) to the resampling (October 1993) of the same three wells (MW-101, MW-102, and MW-103) during the Phase II investigation reveals a general increase in concentrations for chemicals detected in samples from monitoring well MW-103. Analytical results from samples from monitoring well MW-102 during Phase II changed little compared to the Phase I results, and Phase II analytical results from monitoring well MW-101 contained several chemicals not previously detected.

Analytical data for samples from monitoring well MW-103 indicated a concentration increase for benzene (57 mg/l to 72 mg/l), toluene (22.5 mg/l to 43 mg/l), total xylene (1.6 mg/l to 2.7 mg/l), and phenol (59 mg/l to 210 mg/l). A decrease of concentrations was noted for 4-methylphenol (3.6 mg/l to 0.88 mg/l), 2,4-dimethylphenol (4.7 mg/l to 1.3 mg/l), and naphthalene (18 mg/l to 4.4 mg/l). Chlorobenzene, styrene, cumene, 2-methylphenol, benzoic acid, and 2-methylnaphthalene which were detected in the Phase II sample from monitoring well MW-103, were not detected in the Phase I sample.

Only bis(2-ethylhexyl) phthalate, a common laboratory contaminant, was detected in the Phase II analysis of the monitoring well MW-102 sample. No organic contaminants were detected in the Phase I sample from this well.

Analytical data for the samples from monitoring well MW-101 indicated a concentration decrease for cumene (0.260 mg/l to 0.048 mg/l) and naphthalene (0.033 to 0.003 mg/l). However, the Phase II analytical data included positive detections of 2-butanone, benzene, 2-hexanone, toluene, phenol, and fluorene; these compounds were not detected in the Phase I analysis. Acenaphthalene and dibenzofuran levels were slightly higher in the Phase II sample.

The extent of free-phase LNAPL measured in June and October 1993 did not deviate significantly from that observed previously (see Figure 4-9).

TOC, BOD<sub>5</sub>, total hardness, total alkalinity, and dissolved solids analyses were conducted on all shallow groundwater samples (see Table 4-6 and Appendix A). Organic carbon analytical results ranged from 23,100 mg/l in the sample from monitoring well MW-117 to 1 mg/l in the sample from monitoring well MW-108. BOD<sub>5</sub> analytical results ranged from 4,700 mg/l in the sample from monitoring well MW-117 to less than 1 mg/l in the samples from monitoring wells MW-108 and MW-115. The ratio of oxygen to organic carbon required for complete biological degradation of all available organic carbon is 2.6:1 (based on molecular weight). Since the results of BOD<sub>5</sub> are representative of biodegradation oxygen demand, the ratio of BOD<sub>5</sub> to organic carbon indicates the susceptibility of the organic carbon compounds to biodegradation. The analytical results indicate that a significant portion of the organic carbon present in the shallow groundwater (e.g., more than one-half in the monitoring well MW-117 sample) is susceptible to biodegradation under ideal conditions. In the field, biodegradation is expected to be limited by the availability of oxygen and/or nutrients. Total hardness analytical results ranged from 20 to 1,100 mg/l. These results indicate that shallow groundwater hardness ranges from soft to very hard. Similarly, TDS results range from relatively low (110 mg/l in the monitoring well MW-114 sample) to elevated (4,400 mg/l in the monitoring well MW-115 and MW-117 samples).

#### **4.2.2.2 Deeper Groundwater**

Six of the 31 groundwater samples were collected from the newly installed deep wells. These wells are MW-301, MW-302, MW-303, MW-304, MW-305, and MW-306. Tables 4-7 and 4-8 present a summary of the occurrence and distribution of organic chemicals and metals in the deeper groundwater. The distribution of organic chemical results can be found on Figure 4-12.

In general, the same chemicals were detected in the deep groundwater samples as were detected in the shallow groundwater samples. The chemicals detected included acetone, benzene, toluene, ethylbenzene, and total xylenes, phenol and substituted phenol compounds, naphthalene and other PAHs, cumene, and AMS. The only sample that did not contain contamination was the sample from monitoring well MW-304, which is located south of the former Frankford Creek bed and south of the deep low-level collector sewer. The horizontal extent of contamination in the deeper aquifer has not been determined. Nevertheless, no use of this groundwater is believed to occur, as a result of probable discharge to the City of Philadelphia combined sewer system and the Frankford Inlet.

**TABLE 4-7**  
**OCCURRENCE AND DISTRIBUTION OF ORGANIC CHEMICALS IN**  
**PHASE II DEEPER GROUNDWATER SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/l)**

CHEMICAL	FREQUENCY OF POSITIVE DETECTIONS	RANGE OF POSITIVE DETECTIONS
Acetone	2/6	0.52 to 45
2-Butanone	1/5	0.005
Benzene	5/6	0.005 to 45
4-Methyl-2-pentanone	1/6	0.017
Toluene	4/6	0.009 to 19
Chlorobenzene	1/6	0.005
Ethylbenzene	3/6	0.420 to 1.2
Styrene	1/6	0.660
Total xylene	4/6	0.004 to 0.470
Phenol	5/6	0.16 to 3,200
bis(2-chloroethyl)ether	1/6	0.160
2-Methylphenol	4/6	0.017 to 190
4-Methylphenol	5/6	0.021 to 530
2,4-Dimethylphenol	5/6	0.022 to 86
Naphthalene	4/6	0.013 to 0.016
2-methylnaphthalene	2/6	0.012 to 2.6
Acenaphthylene	1/6	0.100
Acenaphthene	2/6	0.007 to 0.43
Dibenzofuran	1/6	0.48
Fluorene	1/6	0.36
Phenanthrene	1/6	0.45
Anthracene	1/6	0.11
Carbazole	1/6	0.14
Fluoranthene	1/6	0.099
Pyrene	1/6	0.067
Cumene	4/6	0.042 to 9.2
Alpha-methyl-styrene	2/6	0.004 to 0.094



**TABLE 4-8**  
**OCCURRENCE AND DISTRIBUTION OF METALS AND OTHER MISCELLANEOUS PARAMETERS**  
**DETECTED IN PHASE II DEEPER GROUNDWATER SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**(All data in mg/l)**

CHEMICAL	FREQUENCY OF POSITIVE DETECTIONS	RANGE OF POSITIVE DETECTION
Aluminum	2/6	0.021 to 0.033
Arsenic	3/6	0.0061 to 0.33
Barium	6/6	0.051 to 0.495
Calcium	6/6	61.3 to 309.0*
Iron	5/6	17.2 to 83.9
Magnesium	6/6	28.5 to 207
Manganese	6/6	0.276 to 25.0
Nickel	5/6	0.022 to 0.047
Potassium	6/6	7.18 to 20.6
Selenium	1/6	0.0016
Sodium	6/6	126 to 612
Vanadium	3/6	0.008 to 0.011
Zinc	4/6	0.007 to 0.010
Carbon Organic	6/6	2 to 62,000 mg/l
BOD <sub>5</sub>	5/6	8 to > 770 mg/l
Total Hardness (as CaCO <sub>3</sub> )	6/6	110 to 1,800
Total Alkalinity (as CaCO <sub>3</sub> )	6/6	22 to 900
Dissolved Solids (18°C)	6/6	660 to 4,300

\* The result is the arithmetic mean of the duplicates.

Benzene, toluene, xylenes, and/or ethylbenzene compounds were detected in the samples from monitoring wells MW-301, MW-302, MW-305, and MW-306. The highest levels of benzene, toluene, and xylene were detected in the sample from monitoring well MW-305 (benzene at 45 mg/l, toluene at 19 mg/l, and total xylene at 5.4 mg/l). Monitoring well MW-305 is screened directly beneath the former benzene, toluene, and xylene refinery. Ethylbenzene was detected at its highest level in the sample from monitoring well MW-302.

Phenol and cresol compounds were detected in all samples from the deep monitoring wells (MW-301, MW-302, MW-303, MW-305, and MW-306) except monitoring well MW-304. The highest levels were detected in the sample from monitoring well MW-305; the levels ranged from 3,200 mg/l for phenol to 86 mg/l for 2,4-dimethylphenol and 530 mg/l for 4-methylphenol. The reported concentration of 4-methylphenol and 2,4-dimethylphenol from samples of MW-305 are at levels greater than 10 percent of their respective solubilities (see Section 5.1.3). The next highest phenol and cresol levels were detected in monitoring well MW-306, with levels ranging from 8.6 mg/l of phenol to 0.86 mg/l for 2-methylphenol. Monitoring well MW-306 is located south of the Frankford Inlet, near an apparent deeper groundwater discharge area.

Naphthalene and other PAH compounds were detected in the samples from monitoring wells MW-303, MW-302, MW-305, and MW-301. The sample with the highest level of naphthalene (16 mg/l) and largest number of detected PAHs is the sample from monitoring well MW-302. The naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene concentrations in the sample from MW-302 were reported at levels exceeding 10 percent of their respective reported solubilities. Also, the reported naphthalene level in the sample from MW-305 is greater than 10 percent of its reported solubility. During the purging of MW-302, the first bailer removed from the well was one-half full (approximately one foot) of a heavier-than-water dark brown oily liquid (DNAPL). When the sample was collected from MW-302, small dark brown oily droplets were noticed settling to the bottom of the bottleware. As noted in Section 3.4.2.2, this well is located in a bedrock depression; thus, the presence of DNAPL is probably related. The extent of the DNAPL detected in monitoring well MW-302 accumulated in this depression is unknown. All of the compounds indicated at levels greater than 10 percent of their respective solubilities also have specific gravities greater than 1, which will cause the compounds to sink (see Section 5.1.1).

Cumene was detected in samples from four deep monitoring wells (MW-301, MW-302, MW-305, and MW-306) and AMS was detected in samples from two wells (MW-302 and MW-306). The highest level of cumene (9.2 mg/l) was detected in well MW-301. The highest level of AMS (0.094 mg/l) was detected in the sample from monitoring well MW-302.

Two compounds, chlorobenzene (at 0.005 mg/l) and bis(2-chloroethyl)ether (at 0.16 mg/l), detected in the sample from monitoring well MW-306 were not detected in samples from any other shallow or deep monitoring wells on site. This well is located on the southeastern area of the site near an apparent deep groundwater discharge area. The discharge area may be receiving recharge from other off-site sources of contamination.

TOC, BOD<sub>5</sub>, total hardness, total alkalinity, and dissolved solids analyses were conducted on all deeper groundwater samples (see Table 4-3 and Appendix A). Organic carbon analytical results ranged from 2 mg/l to 62,000 mg/l in the sample from monitoring well MW-302. BOD<sub>5</sub> analytical results ranged from less than 1 mg/l in the sample from monitoring well MW-304 to greater than 770 mg/l in the sample from monitoring well MW-305. As discussed previously, the ratio of BOD to TOC serves as an indicator for biological degradation potential. Only the ratio for the sample from monitoring well MW-306 exceeded one (1.12), indicating that not all of the organic carbons compounds are readily biodegradable. Total hardness analytical results ranged from 110 to 1,800 mg/l (monitoring well MW-304 and MW-303 results, respectively). The total hardness results indicate that the majority of deep groundwater is hard to very hard. This conclusion is supported by the TDS and alkalinity results.

#### 4.3 SEWER LINE DATA

All Plant stormwater discharges are currently permitted. In addition, discharges of water softener backwash, non-contact cooling water, process wastewater, recovered groundwater, and sanitary wastewater are also permitted either by a City of Philadelphia Wastewater Discharge Permit (No. ALL100060380DS) or an NPDES permit (PA0012017).

AlliedSignal has an NPDES permit (PA0012017) to discharge water softener backwash, non-contact cooling water, and storm runoff from the Plant to the Frankford inlet. Discharge is through one major outfall (001) and four minor outfalls (003, 004, 005, and 006). (Outfall 002 has been blocked off and no longer exists.) The outfall designation and types of water discharged are listed below.

Outfall No.	Types of Wastewater	1990 Average Discharge (gpd)
001	Water softener backwash and noncontact cooling water from the boiler house	22,000
003	Stormwater runoff	700
004	Stormwater runoff	2,500
005	Stormwater runoff	900
006	Stormwater runoff	1,600

The original Allied Frankford NPDES permit was issued on November 5, 1976 and expires on June 1, 1994. Major permit limitations and monitoring requirements after the 1989 reissuance include the following: pH, temperature, and flow.

The Plant was issued a permit (no. ALLI00060380DS) on February 28, 1991 from the City of Philadelphia to discharge process wastewater, recovered groundwater, sanitary wastewater, and some stormwater to the Philadelphia Northeast Water Pollution Control Plant. Regulated discharges via M sewer in 1993 averaged 360,000 gallons per day. Current permit limitations include conventional parameters (e.g., pH and temperature) nonconventional parameters (phenol, acetone, cumene, benzene, and methanol), and the OCPSF categorical effluent standards.

O sewer sampling by AlliedSignal personnel has been performed as part of the NPDES permit reauthorization. Results of samples taken on November 23, 1993 included phenol (0.082 mg/l), naphthalene (0.010 mg/l), chloroform (0.014 mg/l), acetone (0.093 mg/l), and cumene (0.088 mg/l) (see Appendix H). These data indicate that significant groundwater infiltration into O sewer is not occurring (or the detected concentrations would be much greater).

The flow and the percent of the lower explosive limit (LEL) for combustible gases are continuously monitored in the M sewer. The M sewer is sampled prior to its connection with the low-level interceptor sewer, which eventually flows to the Northeast Water Pollution Control Plant. For the six-month period from July 1, 1993 to December 31, 1993, the average LEL level in the M sewer was 0.6 percent, with a maximum of six percent. The city interceptor downstream of the M sewer discharge point is also monitored for LEL. LEL levels of 1.7 percent (average) and 32 percent (maximum) were measured in the interceptor for the same period.

AlliedSignal also routinely samples E sewer, B sewer, and W sewer water. The sampling is performed as part of AlliedSignal's environmental monitoring program and is outside any permit requirements (see Appendix I).

Samples are obtained from W and E sewers (see Figure 2-3) every four hours and are analyzed in the Plant's waste control laboratory for pH, phenol, and total carbon. The B sewer is sampled once per day. Analytical data for a one-month period from May 1, 1993 to June 1, 1993 are summarized in Table 4-9.

Analytical data collected from samples of the W sewer revealed average phenol concentrations of 5.03 ppm and an average mass flow rate of 0.25 pound per hour. Although these data suggest some groundwater infiltration, the W sewer probably does not receive significant groundwater discharge.

**TABLE 4-9**  
**ANALYTICAL DATA FOR E, B, AND W, SEWERS**  
**MAY 1, 1993 TO JUNE 1, 1993**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Sewer	Flow (gpm) Average	pH (SI units)		Phenol (ppm)			Phenol (pounds per hour)			Total Carbon (ppm)		
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
W sewer	110	10.2	8.0	5.0	360	0.0	0.25	20	0.0	60	147.0	17.88
E sewer	5.4	7.4	6.0	530	800	0.0	1.1	2.4	0.0	92.0	2,310.0	25.0
B sewer	12	8.0	6.3	13	28	4.0	0.07	0.16	0.02	93	145.0	47.0

Analytical data from samples of the B sewer effluent reveal average phenol concentrations of 13 ppm and an average mass flow rate of 0.07 pound per hour. B sewer originates on the Plant. There are no process water discharges to it. Therefore, the measured phenol is believed to be due to groundwater infiltration. The hydrogeologic data (Section 3.5.2.6) did not indicate significant areas of groundwater discharge to the B-sewer even though a long portion of the B sewer is below the water table. In summary, data indicate that some groundwater infiltration into the B sewer is occurring, although it is not believed to be significant.

The E sewer analytical data indicated average phenol concentrations of 530 ppm and an average mass flowrate of 1.1 pounds per hour. E sewer also originates on the Plant, and there are no process water discharges to this sewer. Therefore, the measured phenol is believed to be due to groundwater infiltration. The phenol concentrations typically decreased whenever flow increased (see Appendix I) possibly indicating a dilution of the hypothetical groundwater discharge. The Phase II hydrogeologic data indicate a significant groundwater discharge point occurring near or along the E sewer near well MW-201.

#### **4.4 DRINKING WATER LINE DATA**

The Plant has a program in place to prevent Plant drinking water supply lines from being affected by contamination. As of December 1992, back-flow prevention devices were in place on all of the drinking water lines. Sampling of the water fountains and other water stations (i.e., ice machines, restrooms, and sinks) occurred most recently on January 18, 1993. Fifteen samples and a trip blank were analyzed for inorganic contaminants, VOCs (EPA 524.2), semivolatile organic compounds (EPA Method 525), and coliform. Sample results are included in Appendix J. The sample results indicated that the water supply was not affected by on-site contamination or Plant operations.

## 5.0 CONTAMINANT FATE AND TRANSPORT

Various aspects of contaminant fate and transport at the Plant are discussed in this section. Properties that affect contaminant migration are presented in Section 5.1. Section 5.2 presents a brief discussion of contaminant persistence.

### 5.1 CHEMICAL AND PHYSICAL PROPERTIES OF SITE CONTAMINANTS

Various chemical and physical properties of chemicals detected during the RFI are presented and discussed in this section. The complete analytical database is presented in Appendix A; results are discussed in Section 4.0. These parameters are used to estimate the environmental behavior of site chemicals. Physical and chemical properties of the organic compounds are presented in Table 5-1. Environmental fate-related properties of inorganics are presented in Table 5-2.

Empirically determined literature values of the water solubility, octanol/water partition coefficient ( $K_{ow}$ ), organic carbon/water partition coefficient ( $K_{oc}$ ), vapor pressure, bioconcentration factor (BCF), and specific gravity are presented, where available. Calculated values were obtained using approximation methods where noted, if literature values were unavailable.

#### 5.1.1 Specific Gravity

Specific gravity is the ratio of the weight of a given volume of pure chemical at a specified temperature to the weight of the same volume of water at the given temperature. Its primary use is to determine whether a contaminant will have a tendency to float or sink in water if it is present as a pure compound or at very high concentrations. Contaminants with a specific gravity greater than 1 will tend to sink, whereas contaminants with a specific gravity less than 1 will tend to float. However, solubility also can affect sinking and floating tendencies, as discussed in Section 5.1.3. Of the contaminants commonly detected during the RFI, cumene, benzene, toluene, ethylbenzene, and xylene have specific gravities less than 1.0, and the cresols (methylphenols) have reported specific gravities greater than 1.0. Many of the PAHs detected in the well MW-302 sample also have specific gravities greater than 1.0. This is not unexpected, considering that DNAPL was noted in this well.

**TABLE 5-1**  
**PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC COMPOUNDS**  
**DETECTED IN ENVIRONMENTAL SAMPLES**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

CHEMICAL	MOL WT <sup>(1)(3)</sup> (g)	SOL <sup>(1)(2)(3)</sup> (mg/l)	LOG K <sub>ow</sub> <sup>(2)(3)(4)</sup>	VP <sup>(1)(2)(3)</sup> (mm Hg, 20C)	H <sup>(1)(3)</sup> (atm m <sup>3</sup> /mol)	BCF <sup>(1)(6)(7)</sup>	SP GR <sup>(2)(5)</sup> (@ 20C)	K <sub>oc</sub> <sup>(1)</sup>
Acetone	58.08	680,000	-0.24	270	3.43E-5	3E-1	0.791	9.2
2-Butanone	72.1	353,000	0.26	78	2.08E-5	6E-1	0.805	17
Benzene	78.12	1,780(25C)	2.13	95.2	5.5E-3	7.84	0.8786	65
Toluene	92.13	534.8(25C)	2.69(20C)	28.7	6.66E-3	25	0.867	300
Ethylbenzene	106.16	152	3.15	7	6.6E-3	66.8	0.867	1.1E3
Xylenes	106.16	187	2.77 - 3.2	6.5	4.33E-3	1.5E-2	0.86-0.88	248
Styrene	104.14	300	3.16	5	2.28E-3	1.2	0.9045 (25C)	568
2-Methylphenol	108.1	8,700	1.95	2.4E-1	3.92E-6	11	1.041	24.5
4-Methylphenol	108.1	4,400	1.92/1.94	4E-2	1.29E-6	11	1.0347	24.3
2,4-Dimethylphenol	122.2	590(25C)	2.42	6.2E-2	1.7E-5	75	1.036	96
Trans-1,2-Dichloroethene	96.94	600	1.48	3.26E-2	6.73-2	48	1.26	59
Acetophenone	120.15	5,500	1.58	1 (15C)	---	5-9	1.03	21-269 <sup>(6)</sup> ; 35 <sup>(8)</sup>
Phenol	94.11	93,000	1.46	3.41E-1	4.54E-7	9.4	1.07	14.2
Chlorobenzene	112.56	500	2.84	11.7	3.58E-3	164	1.1066	330
Cumene	120.19	50 (20C)	3.66	3.2	1.46E-2	35.5	0.862	2,800 + <sup>(6)</sup>
alpha-Methylstyrene	118.18	560(25C) <sup>(6)</sup>	3.35 <sup>(6)</sup>	1 (74C)	---	29.5	0.9082	135-1,585 <sup>(6)</sup>
4-Methyl-2-Pentanone	100.2	17,000	1.19 <sup>(6)</sup>	6	4.16E-5	5.2	0.8017	113
Acenaphthylene	152.20	3.93 (25C)	4.07	9.12E-4 (25C) <sup>(6)</sup>	1.14E-4	128 - 575	0.899	950-3,315 <sup>(6)</sup>



TABLE 5-1 (continued)  
 PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC COMPOUNDS  
 ALLIEDSIGNAL FRANKFORD PLANT  
 PAGE 2 OF 3

CHEMICAL	MOL WT <sup>(1)(3)</sup> (g)	SOL <sup>(1)(2)(3)</sup> (mg/l)	LOG K <sub>ow</sub> <sup>(2)(3)(4)</sup>	VP <sup>(1)(2)(3)</sup> (mm Hg, 20C)	H <sup>(1)(3)</sup> (atm m <sup>3</sup> /mol)	BCF <sup>(1)(6)(7)</sup>	SP GR <sup>(2)(5)</sup> (@ 20C)	K <sub>oc</sub> <sup>(1)</sup>
Acenaphthene	154.2	3.42 (25C)	3.92	1.55E-3 (25C)	9.1E-5	1.8E3	1.0242	4.6E3
Dibenzofuran	168.2	10	4.12	4.4E-3 (25C) <sup>(6)</sup>	---	82-2,858	10.886 (99/4)	4,600-6,350 <sup>(6)</sup>
Fluorene	116.2	1.69 (25C)	4.18	7.1E-4	6.4E-5	3.8E3	1.203	7.3E3
Phenanthrene	178.23	0.816 (21C)	4.46	1 (118.2C)	3.93E-5	---	1.025	2.3E4 <sup>(6)</sup>
Anthracene	178.2	0.045 (25C)	4.45	1.7E5 (25C)	8.6E-5	4.7E3	1.283	1.4E4; 26,000 <sup>(8)</sup>
Fluoranthene	202.3	0.26 (25C)	5.33	5E-6 (25C)	6.5E-6	1.2E4	1.252	3.8E4
Pyrene	202.3	0.13 (25C)	5.18	2.5E-6 (25C)	5.1E-6	1.2E4	---	3.8E4
Naphthalene	128.2	31.7 (25C)	3.01/3.45	8.7E-3 (25C)	4.6E-4	4.2E2	1.152	9.4E2
2-Methylnaphthalene	142.2	26 (25C)	3.86	10 (105C)	---	28-300	0.994	8,500 <sup>(6)</sup>
Benz(a)anthracene	228.28	0.0057	5.61	2.2E-8	1E-6	5.3E4	---	2E5
Chrysene	228.3	0.0018 (25C)	5.61	6.3E-9 (25C)	1.05E-6	5.3E4	1.274	2E5
Benzo(b)fluoranthene	252.3	0.0014 (25C)	6.57	5E-7	1.22E-5	1.4E5	---	5.5E5
Benzo(k)fluoranthene	252.3	0.0043 (25C)	6.84	5E-7	3.87E-5	1.4E5	---	5.5E5
Benzo(a)pyrene	252	0.0038 (25C)	5.98	5.6E-9	4.9E-7	1.09E4	---	5.5E6
Indeno(1,2,3-c,d)pyrene	276.3	0.00053 (25C)	7.66	1E-10	6.95E-8	3.5E5	---	1.6E6
Dibenz(a,h)anthracene	278.4	0.0005 (25C)	5.97	1E-10	7.3E-8	6.9E5	---	3.3E6
Benzo(g,h,i)perylene	276	0.00026 (25C)	7.23	1.03E-10 (25C)	1.44E-7	3.5E5	---	1.6E6
Di-n-butyl phthalate	278.3	13 (25C)	5.2	1E-5 (25C)	2.8E-7	4.7E4	1.0465	1.7E5
Bis(2-ethylhexyl) phthalate	390.62	0.40 (25C)	5.3	2E-7	3E-7	2.3E8	0.99	2E9

TABLE 5-1 (continued)  
 PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC COMPOUNDS  
 ALLIEDSIGNAL FRANKFORD PLANT  
 PAGE 3 OF 3

CHEMICAL	MOL WT <sup>(1)(3)</sup> (g)	SOL <sup>(1)(2)(3)</sup> (mg/l)	LOG K <sub>ow</sub> <sup>(2)(3)(4)</sup>	VP <sup>(1)(2)(3)</sup> (mm Hg, 20C)	H <sup>(1)(3)</sup> (atm m <sup>3</sup> /mol)	BCF <sup>(1)(6)(7)</sup>	SP GR <sup>(2)(5)</sup> (@ 20C)	K <sub>oc</sub> <sup>(1)</sup>
Bis(2-chloroethyl) ether	143.02	10,200	1.58	0.7	1.3 X 10 <sup>-5</sup>	6.9	1.22 (20/4c)	13.9
Chloroform	119.38	8,200	1.97	150	3.8 X 10 <sup>-3</sup>	5.56	1.489	44
1,1,1-Trichloroethane	133.41	4,400	2.17	100	1.8 X 10 <sup>-2</sup>	81	1.35 (20/4c)	178
Carbazole	167.21	- - -	3.51	400 (323C)	- - -	- - -	1.10 (18/4c)	- - -
2-Hexanone	100.2	35,000	1.38	2	7.52 x 10 <sup>-6</sup>	3.3	0.830 (0/4c)	75
Hexachloroethane	236.76	50 (22C)	3.34	0.4	2.49 X 10 <sup>-3</sup>	- - -	2.9 (20/4c)	2.0 X 10 <sup>-4</sup>

MOL WT = Molecular weight  
 BCF = Bioconcentration or bioaccumulation factor; freshwater species

- (1) Weast, 1988
- (2) Versar, 1979
- (3) EPA, August 19, 1983a; EPA, August 19, 1983c; EPA, February 18, 1986; EPA, August 19, 1983d; EPA, April 10, 1986; EPA, August 19, 1983e; EPA, October 1980a; EPA October 1980b
- (4) Dragun, 1988

**TABLE 5-2**  
**PROPERTIES OF INORGANIC COMPOUNDS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

METAL	MOL WT (g)(1)	BCF		$K_d^{(4)}$ (ml/g)	DESCRIBED ENVIRONMENTAL FATE <sup>(2)</sup>
		(2)	(3)		
Arsenic	74.92	333	0 - 17	1 - 8.3	Sorption important
Barium	137.34	---	---	---	---
Beryllium	9.0122	100	19	---	Sorption important; many species mobile
Cadmium	112.4	1,000 - 4,000	2 - 3,520	1.3 - 27	Bioaccumulation, sorption important
Chromium	51.996	70 - 4,000	< 1 - 2.8	III: 470 - 150,000 VI: 1.2 - 1,800	Cr VI soluble, mobile; Cr III insoluble; sorption important
Copper	63.54	12 - 30,000	0 - 2,000	1.4 - 333	Sorption, bioaccumulation important
Lead	207.19	60 - 200	42 - 1,700	4.5 - 7,640	Sorption, bioaccumulation important
Manganese	55	---	---	0.2 - 10,000	---
Mercury	200.59	1,000 - 100,000	4,994 - 64,000	---	Some insoluble species; sorption, metabolism, bioaccumulation important
Nickel	58.71	40 - 100	0.8 - 192	---	Soluble species exist; some bioaccumulation, sorption
Selenium	78.9	400-800	15-18	---	Sorption, bioaccumulation important
Vanadium	50.942	---	---	---	---
Zinc	65.38	1,000 - 40,000	51 - 1,130	0.1 - 8,000	Sorption, bioaccumulation important

$K_d$  = Distribution coefficient

MOL WT = Molecular weight

BCF = Bioconcentration of bioaccumulation factor; freshwater species

(1) Weast, 1988

(2) Versar, 1979

(3) EPA, August 19, 1983a; EPA, August 19, 1983c; EPA, February 18, 1986; EPA, August 19, 1983d; EPA, April 10, 1986; EPA, August 19, 1983e; EPA, October 1980a; EPA October 1980b

(4) Dragun, 1988

### **5.1.2 Vapor Pressure**

Vapor pressure provides an indication of the rate at which a chemical volatilizes from both soil and water. It is of primary significance at environmental interfaces, such as surface soil/air and surface water/air. Volatilization is not as important when evaluating contaminated groundwater and subsurface soils. Of the commonly detected site contaminants, vapor pressure for compounds such as acetone and benzene is generally higher than vapor pressure for PAHs and phthalates. Chemicals with higher vapor pressure are expected to enter the atmosphere much more readily than chemicals with lower vapor pressure. Volatilization can be a significant loss process for volatile organic compounds in surface media or sewer lines. At the Plant, approximately 60 to 70 percent of soils are covered by asphalt, cement, or buildings, which severely limits the potential for volatilization from surface soils. Most of the remainder of the site is overlain by gravel.

### **5.1.3 Solubility**

The rate at which a chemical is leached from contaminated soils by infiltrating precipitation is contingent upon its water solubility. More soluble chemicals are more readily leached than less soluble chemicals. The water solubilities presented in Table 5-1 indicate that the BTEX compounds, phenol, and acetone are several orders of magnitude more water soluble than the PAHs and the phthalates detected at the site. Cumene is intermediate in solubility between the BTEX compounds and PAHs. Naphthalene and 2-methylnaphthalene are the most soluble of the PAHs, but their solubility still does not approach that of compounds such as acetone and phenol. Solubility can also affect the sinking and floating behavior of chemicals. For example, cumene will float when present at concentrations exceeding its solubility.

In the laboratory, the solubility of a chemical is generally determined by placing an excess of chemical in very pure water and allowing it to equilibrate at a constant temperature with mixing and agitation. The chemical composition of water in a soil medium, however, is different than very pure water because of the solution of minerals and other influences. The water composition, along with other factors, determines the solubility of a substance in soil water. The factors that have been determined to influence the solubility of a substance are temperature, pH, dissolved organic matter, dissolved salts, the purity of the chemical, redox potential, and the relative concentrations of other substances in solution. The interactions of these factors make it difficult to predict the solubility of a substance in soil water. From this list of factors, the effects of temperature, pH, dissolved salts, and dissolved organic matter are discussed below.

## Temperature

The effect of temperature on the solubility of substances is usually profound. For most chemicals, an increase in temperature results in an increase in solubility. A few chemicals, such as p-dichlorobenzene, show a decrease in solubility with increasing temperature over certain temperature ranges.

## Dissolved Organic Matter

Several investigations have reported an increase in solubility in the presence of dissolved organic matter. Among the compounds that exhibited this effect were n-alkanes, DDT, and phthalate esters. The solubilities of aromatic hydrocarbons were reported to be unaffected by the presence of dissolved organic matter.

## pH

The pH of soil water also affects the solubility of most chemicals. The solubility of organic acids may be expected to increase with increased pH. Organic bases, on the other hand, behave in the opposite way. The solubility of neutral organic chemicals (e.g., alkanes and chlorinated hydrocarbons) is also reported to be affected by pH, although the type and magnitude of the effect are compound dependent.

## Dissolved Salts

The presence of dissolved inorganic salts generally reduces the solubility of both organic and (other) inorganic substances. This "salting out" effect can be significant. Also, relatively soluble substances (e.g., sodium stearate) can be converted to relatively insoluble substances (e.g., calcium or magnesium stearate) by cation exchange with groundwater-borne ions. Dissolved salts may also affect the stability of emulsions and other colloidal mixtures. A similar relationship has been observed for the partitioning of dissolved organic compounds between water and soil/rock organic carbon matter in many hydrogeological environments.

### **5.1.4 Octanol/Water Partition Coefficient ( $K_{ow}$ )**

The  $K_{ow}$  is a measure of the equilibrium partitioning of chemicals between octanol and water. A linear relationship between the  $K_{ow}$  and the uptake of chemicals by fatty tissues of aquatic organisms [the bioconcentration factor (BCF)] has been determined. In fact, some BCFs presented in Table 5-1 are derived from the  $K_{ow}$  where experimental data were not available. The log  $K_{ow}$  (the form in which this property is typically reported) is provided for organic chemicals on Table 5-1. It can be seen that PAHs partition to the non-aqueous phase (forming DNAPL) much more readily than compounds such as acetone and pyridine.

### 5.1.5 Bioconcentration Factor (BCF)

BCFs represent the ratio of aquatic animal tissue concentration to water concentration. The ratio is both contaminant and species specific. Typically, literature values may be used or the BCF may be derived from the  $K_{ow}$ . It can be seen from the values in Tables 5-1 and 5-2 that the VOCs and phenols are not as likely to bioconcentrate as chemicals such as PAHs. It should be noted that PAHs can be metabolized by vertebrates, and PAH bioconcentration is more likely for invertebrates (Versar, 1979).

### 5.1.6 Henry's Law Constant

Both the vapor pressure and the water solubility are of use in determining volatilization rates from surface water bodies, sewers, and groundwater. The ratio of these two parameters, the Henry's Law constant, is used to calculate the equilibrium contaminant concentrations in the vapor versus the liquid phases for the dilute solutions commonly encountered in environmental settings. In general, chemicals having a Henry's Law Constant of less than  $5 \times 10^{-6}$  atm-m<sup>3</sup>/mol [such as benzo(a)pyrene] should volatilize very little and be present only in minute amounts in the atmosphere or in soil gas. For chemicals with a Henry's Law Constant greater than  $5 \times 10^{-3}$  atm-m<sup>3</sup>/mol (such as cumene and benzene), volatilization and diffusion in soil gas could be significant.

### 5.1.7 Organic Carbon Partition Coefficient ( $K_{oc}$ )

The  $K_{oc}$  indicates the tendency of a chemical to bind to the organic carbon present in soil or sediment. Chemicals with high  $K_{oc}$  values generally have low water solubilities and vice versa. This parameter may be used to infer the relative rates at which the more mobile chemicals (benzene, phenol, styrene) are transported in the groundwater. Chemicals such as PAHs and phthalates are relatively immobile in the environment and are preferentially bound to the soil phase. These compounds are not subject to groundwater transport to the extent that compounds with higher water solubilities are.  $K_{oc}$ s are given in Table 5-1.

### 5.1.8 Distribution Coefficient ( $K_d$ )

The  $K_d$  is a measure of the equilibrium distribution of a chemical or ion in soil/water systems. The distribution of organic chemicals is a function of both the  $K_{oc}$  and the amount of organic carbon in the soil. Generally,  $K_d$ s for organic chemicals would be expected to be higher for the organic silt-clay unit than the sand and gravel unit (i.e., organic chemicals would be expected to more strongly sorb to the silt-clay unit materials than the sand and gravel unit materials). Since the organic content of the unconsolidated materials at the Plant varies widely, organic chemical  $K_d$ s would also be expected to vary widely.

For ions (e.g., metals), the  $K_d$  is the ratio of the concentration absorbed on soil surfaces to the equilibrium concentration in water.  $K_d$ s for metals vary over several orders of magnitude because the  $K_d$  is dependent on the size and charge of the ion and the soil properties governing exchange sites on soil surfaces. Coulomb's Law predicts that the ion with the smallest hydrated radius and the largest charge will be preferentially accumulated over ions with larger radii and smaller charges.  $K_d$  ranges for several metals are shown in Table 5-2.

## 5.2 CONTAMINANT PERSISTENCE

The persistence of various classes of site contaminants is discussed in this section. Several transformation mechanisms can affect contaminant persistence in the environment, such as hydrolysis, biodegradation, photolysis, and oxidation/reduction reactions.

In general, photolytic degradation is not considered to be a relevant degradation mechanism for compounds at the Plant; virtually all the contamination is located in the subsurface soil/fill and groundwater.

Generally, organic molecules are subject to several chemical reactions under environmental conditions. Such reaction mechanisms include acid/base reactions, addition, elimination, and hydrolysis. However, monocyclic aromatics and chlorinated alkanes and alkenes are not particularly amenable to the majority of these degradation mechanisms. As can be seen in Table 5-3, hydrolysis is also considered to be negligible for PAHs. Alkyl halides and phthalates can be more susceptible (Versar, 1979; EPA, December 1982).

Hydrolysis can occur under acidic, basic, or neutral conditions. Because the groundwater pH is generally neutral (5.9 to 8.25 SI units), neutral hydrolysis for certain compounds could occur under the appropriate conditions.

Biodegradation is a potential environmental fate mechanism for most of the prominent Plant contaminants (benzene, phenol, cumene, cresols, pyridine, and PAHs). Reported experimental values for biodegradation are shown in Table 5-3, where available. Preferentially, results obtained from a soil-groundwater system field observation were used. It can be seen that 2,4-dimethylphenol, cumene, phenol, and naphthalene are generally expected to have low persistence in the environment, as opposed to compounds such as bis(2-ethylhexyl) phthalate (BEHP) and benzo(a)pyrene. The degree that biodegradation is occurring at the Plant was not directly assessed during the Phase II RFI. However, it should be noted that some contaminant (e.g., naphthalene) concentrations at certain locations (e.g., monitoring well MW-122) may exceed toxic thresholds above which microbes cannot exist. Also, given the relatively low groundwater dissolved oxygen levels measured during the Phase II RFI, biodegradation of contaminants in groundwater is likely to be oxygen limited.

**TABLE 5-3**  
**PERSISTENCE-RELATED PROPERTIES OF SELECTED ORGANIC COMPOUNDS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

CHEMICAL	HYDROLYSIS CONSTANTS <sup>(1)</sup>				BIODEGRADATION <sup>(2)</sup>
	$K_{acid}$ (M <sup>-1</sup> hr <sup>-1</sup> )	$K_{base}$ (M <sup>-1</sup> hr <sup>-1</sup> )	$K_{neutral}$ (hr <sup>-1</sup> )	Ref. Temp. (C)	
Benzene	0	0	0	- - -	68/110-day T 1/2 (sgw, fo); 100% 434d (sgw, fo)
Toluene	0	0	0	- - -	37-39d T 1/2, 100% 80d (sgw, fo)
Ethylbenzene	0	0	0	- - -	37 d T 1/2 (sgw, fo)
Xylenes	NR	NR	NR	- - -	11-37d T 1/2 (sgw, fo)
Styrene	NR	NR	NR	- - -	2.3-12% per w (si, nmf)
2-Methylphenol	NR	NR	NR	- - -	Total methylphenols: 4-d T 1/2 (sgw, fo)
4-Methylphenol	NR	NR	NR	- - -	(see above)
2,4-Dimethylphenol	0	0	0	- - -	100% 7d (scf, sdw)
Pyridine	NR	NR	NR	- - -	100% 8d (si, nmf)
Trans-1,2-Dichloroethene	0	0	0	- - -	100 % 50 hr (swi, nmm); 139-d T 1/2 (swi, nmf)
Acetophenone	NR	NR	NR	- - -	4d T 1/2 (sgw, fo)
Phenol	0	0	0	- - -	97% 7d (scf, sdw)
Chlorobenzene	0	0	0	- - -	37d T 1/2 (sgw, fo)
Cumene	NR	NR	NR	- - -	100% 11d (bgw, nmf); 100% 192 hrs (sp, nmf)
alpha-Methylstyrene	NR	NR	NR	- - -	
Acenaphthylene	0	0	0	- - -	96% 7d (scf, sdw)
Acenaphthene	0	0	0	- - -	98% 7d (scf, sdw)



**TABLE 5-3 (continued)**  
**PERSISTENCE-RELATED PROPERTIES OF SELECTED ORGANIC COMPOUNDS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 2 OF 3**

CHEMICAL	HYDROLYSIS CONSTANTS <sup>(1)</sup>				BIODEGRADATION <sup>(2)</sup>
	K <sub>acid</sub> (M <sup>-1</sup> hr <sup>-1</sup> )	K <sub>base</sub> (M <sup>-1</sup> hr <sup>-1</sup> )	K <sub>neutral</sub> (hr <sup>-1</sup> )	Ref. Temp. (C)	
Dibenzofuran	NR	NR	NR	---	100% 1w (si, naf)
Fluorene	0	0	0	---	74% 7d (scf, sdw)
Phenanthrene	0	0	0	---	100% 7d (scf, sdw)
Anthracene	0	0	0	---	35% 7d (scf, sdw)
Fluoranthene	0	0	0	---	0% 7d (scf, sdw)
Pyrene	0	0	0	---	41% 7d (scf, sdw)
Naphthalene	0	0	0	---	100% 7d (scf, sdw); 110d T1/2 (si, nmf)
2-Methylnaphthalene	NR	NR	NR	---	100% 9d (scf, sdw); 100% 1w (si, naf)
Benz(a)anthracene	0	0	0	---	8% 7d (scf, sdw)
Chrysene	0	0	0	---	3% 7d (scf, sdw)
Benzo(b)fluoranthene	0	0	0	---	360 - 610d T 1/2 (si, nmf)
Benzo(k)fluoranthene	0	0	0	---	910 - 1,400d T 1/2 (si, nmf)
Benzo(a)pyrene	0	0	0	---	28% 16 mo (si, nmf)
Indeno(1,2,3-c,d)perylene	0	0	0	---	600 - 730d T 1/2 (si, nmf)
Dibenz(a,h)anthracene	0	0	0	---	750 - 940d T 1/2 (si, nmf)
Benzo(g,h,i)perylene	0	0	0	---	590 - 650d T 1/2 (si, nmf)
Di-n-butyl Phthalate	7.92E-3	79.2	0	30	100% 7d (scf, sdw)
Bis(2-ethylhexyl) phthalate	4E-5	0.4	0	30	0% 7d (scf, sdw)
Bis(2-chloroethyl) ether	---	---	4 x 10 <sup>-6</sup>	25	100% 7d (scf, sdw)

**TABLE 5-3 (continued)**  
**PERSISTENCE-RELATED PROPERTIES OF SELECTED ORGANIC COMPOUNDS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PAGE 3 OF 3**

CHEMICAL	HYDROLYSIS CONSTANTS <sup>(1)</sup>				BIODEGRADATION <sup>(2)</sup>
	K <sub>acid</sub> (M <sup>-1</sup> hr <sup>-1</sup> )	K <sub>base</sub> (M <sup>-1</sup> hr <sup>-1</sup> )	K <sub>neutral</sub> (hr <sup>-1</sup> )	Ref. Temp. (C)	
Chloroform	0	0.23 (25°C)	2.5 x 10 <sup>-9</sup>	25	48% 7d (scf, sdw)
1,1,1-Trichloroethane	0	- - -	1.7 x 10 <sup>-4</sup>	25	300d T1/2 (sgw, fo), 26% 7d (scf, sdw)
Hexachloroethane	0	0	0	- - -	100% 7d (scf, sdw)

References

(1) EPA, December 1982

(2) Dragun, 1988

NR = Not reported; chemicals of this type are generally resistant to hydrolysis.

d = day(s)

scf = static-culture flask

sdw = settled domestic wastewater as inoculum

sgw = naturally occurring soil-groundwater system

fo = field observation

T1/2 = half-life

swi = soil-water incubation study

w = week(s)

si = soil incubation

nmf = natural microbial flora as inoculum

hr = hour

nmm = natural microbial flora; methanogenic

conditions

bgw = batch test using groundwater

sp = soil percolation study

naf = natural acclimated microbial flora

### **5.3 CONTAMINANT PATHWAYS**

The migration of site chemicals via shallow groundwater transport to other groundwater units is possible from dissolved, LNAPL, and DNAPL constituents. Organic chemicals have been detected in all of the deeper wells located on Plant property.

As discussed in Sections 3.0 and 4.0 groundwater infiltration into the sanitary sewer lines at and around the Plant is likely. Analyses that have been conducted for NPDES permitting indicate that storm water effluent does not contain considerable quantities of groundwater contaminants. However, samples of the water contained in the B,E, and W, sewers were noted to contain phenol, implying some degree of infiltration into these sewer lines. Also, groundwater discharge areas coinciding with Plant sanitary sewer lines were noted. These sewer lines discharged into City of Philadelphia combined sewer lines.

As discussed in Section 3.0 and 4.0, discharge of groundwater via seepage is noted to be occurring at one location along the northern bank of the Frankford Inlet. Water-level variation closely related to tidal fluctuations was noted in monitoring wells and piezometers along the south side of the inlet. (A similar effect was not observed in shallow wells along the north bank, presumably as a result of the impermeability of the soils.) Therefore, groundwater discharge to the inlet from the southern bank may also be occurring.

## **6.0 HEALTH AND ENVIRONMENTAL ASSESSMENT**

This section presents a health and environmental assessment for certain contaminated media at the Plant, in accordance with the RFI Plan (NUS, 1991). The purpose of the assessment is to evaluate the potential risk associated with exposure to site chemicals by human and environmental receptors. Evaluation of risk includes identification of potential routes and mechanisms of exposure, identification of receptors, assessment of chemical toxicity, and quantitation of exposures and the associated risks. This section also identifies potentially applicable criteria or regulatory standards. Contaminant pathways were identified in Section 5.3.

There are no identified actual or potential users of groundwater at or near the Plant, so exposure to groundwater used as drinking water will not be considered. Groundwater chemical transport to surface discharge points and to infiltration points along the City combined sewer system (including Plant sanitary sewers) is considered likely, however, as described previously. The combined sewers discharge to the Northeast Water Pollution Control Plant. These pathways are evaluated further in the following subsections.

### **6.1 CITY SEWER PATHWAYS**

Although no direct contact to the groundwater discharged into the City combined sewers is expected to occur under normal circumstances, volatilization of groundwater chemicals may result in exposure of human receptors via inhalation. Contact can be reasonably assumed to occur only at the manhole cover vents and at the discharge outfall at the sewage treatment plant. Backflow of sewer vapors into residences is prevented by drain traps and similar plumbing fixtures.

#### **6.1.1 Vapor Emissions Modeling**

Direct measurement of vapor emissions from chemicals in groundwater was not performed during the RFI field investigations. Consequently, vapor emissions modeling has been utilized to estimate exposure concentrations for potential chemicals of concern via the inhalation route. The model has been selected to quantify ambient vapor concentrations during releases, considering the primary release and transport mechanisms.

The groundwater chemical vapor emissions have been estimated based on the assumption of complete volatilization within the sewer and escape only at the exposure points (i.e., manhole cover vent holes and at the treatment plant outfall).

The following paragraphs describe the derivation and use of the vapor emission model. Results of the modeling are used to estimate contact concentrations for each of the applicable exposure scenarios. Detailed discussions of the model are presented in Appendix K. Results of the modeling and sample calculations are also presented in Appendix K.

Vapor emissions modeling for groundwater infiltrating into Plant sewers is performed by assuming that all groundwater chemicals entering the sewer volatilize to the extent governed by Henry's Law. The Henry's Law Constant can be determined empirically or can be estimated based on the chemical-specific ratio of the vapor pressure to the aqueous solubility. A summary of the chemical-specific physical transport values used for the vapor emissions modeling is provided in Table 6-1.

The emissions model also considers the dilution of infiltrating groundwater by wastewater already present in the City sewer system. Based on the rough estimates of shallow groundwater flow into the sewers presented in Section 3.0, approximately 20,000 gallons infiltrate the E sewer, Frankford Inlet sewers, the low-level collector sewer, and the sewers near former Milnor and Granite Streets on a daily basis.

According to Gene Mudry, of the Philadelphia Sewer Department (Mudry, 1994), the average daily flow in the Frankford Low-Level Collector sewer is approximately 25.4 cubic feet per second (16.4 million gallons per day). Using the estimates that are available, a dilution factor of  $1.2 \times 10^{-3}$  is obtained as the ratio of infiltrating groundwater to total flow in the Frankford Low-Level Collector sewer.

Maximum concentrations of detected chemicals in monitoring wells MW-103, MW-106, MW-109, MW-111, MW-113, and MW-117 were used as the chemical concentrations infiltrating the sewers for the emission model. These well locations were selected for the modeling based on the availability of analytical data and because of their proximity to the sewers that are likely to be subject to groundwater infiltration. The maximum concentrations were then adjusted to account for dilution, and corresponding partial pressures for the volatilized chemicals were obtained based on Henry's Law. The Ideal Gas Law was then used to determine the chemical-specific mass concentrations in air.

The modeled vapor concentrations for groundwater constituents were used for evaluation of risks by receptors exposed to vapors at the manhole cover vents at the intersection of Lefevre and Gaul Streets near the Plant and at the sewage treatment plant outfall. No dilution or hydrodynamic dispersion effects are considered in either exposure scenario; therefore, the concentrations determined are those that were used in the exposure assessment. The dilution factor cited above is conservative for the adult exposure scenario at the treatment plant, because it neglects flows from other sewer lines that mix with the low-level collector flow prior to reaching or at the Plant.

TABLE 6-1

**PHYSICAL AND CHEMICAL TRANSPORT DATA  
GROUNDWATER CHEMICALS  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

Chemical	Molecular Weight (gm/mol)	Vapor Pressure Data (mm Hg @ °C)		Henry's Law Constant (atm-m <sup>3</sup> /mol)
Acetone	58.08	270 @ 30	-	4.28x10 <sup>-5</sup>
Benzene	78.12	95.2 @ 25	-	5.5x10 <sup>-3</sup>
Cumene (Isopropylbenzene)	120.19	3.2 @ 20	-	1.46x10 <sup>-2</sup>
Ethylbenzene	106.17	5 @ 13.9	10 @ 25.9	6.6x10 <sup>-3</sup>
α-Methylstyrene	118.19	1.54 @ 25	-	5.91x10 <sup>-3</sup>
Styrene	104.14	5 @ 20	-	2.28x10 <sup>-3</sup>
Toluene	92.1	10 @ 6.4	20 @ 18.4	6.66x10 <sup>-3</sup>
Xylenes	106.17	5 @ 15.5	10 @ 27.3	4.33x10 <sup>-3</sup>
Acenaphthene	154.21	10 @ 131	760 @ 278	9.1x10 <sup>-5</sup>
Acenaphthylene	152.20	0.029 @ 20	760 @ 265	1.45x10 <sup>-3</sup>
Anthracene	178.23	1.95x10 <sup>-4</sup> @ 25	1 @ 145	8.6x10 <sup>-5</sup>
Carbazole	167.21	400 @ 323	760 @ 355	NA
Dibenzofuran	168.00	ND	ND	NA
Fluoranthene	202.00	5x10 <sup>-6</sup> @ 25	760 @ 375	6.5x10 <sup>-6</sup>
2,4-Dimethylphenol	122.16	1 @ 51.8	5 @ 78	1.7x10 <sup>-5</sup>
Fluorene	166.00	0.017 @ 25	10 @ 146	6.4x10 <sup>-5</sup>

**TABLE 6-1**  
**PHYSICAL AND CHEMICAL TRANSPORT DATA**  
**GROUNDWATER CHEMICALS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
**PAGE 2 of 2**

Chemical	Molecular Weight (gm/mol)	Vapor Pressure Data (mm Hg @ °C)		Henry's Law Constant (atm-m <sup>3</sup> /mol)
2-Methylnaphthalene	142.19	8.3x10 <sup>-3</sup> @ 25	10 @ 105	4.99x10 <sup>-4</sup>
2-Methylphenol	108.1	0.24 @ 25	-	3.92x10 <sup>-6</sup>
4-Methylphenol	108.1	0.04 @ 20	-	3.92x10 <sup>-7</sup>
Naphthalene	128.16	1 @ 52.6	5 @ 74.2	4.6x10 <sup>-4</sup>
Phenanthrene	178.22	2.1x10 <sup>-4</sup> @ 25	1 @ 118.2	2.26x10 <sup>-4</sup>
Phenol	94.11	0.341 @ 25	-	4.54x10 <sup>-7</sup>
Pyrene	202.26	2.5 @ 200	760 @ 393	5.1x10 <sup>-6</sup>

ND - No data available.

NA - Parameter not applicable, vapor transport modeling not performed.

Table 6-2 presents a summary of the results of the groundwater vapor emissions modeling.

### **6.1.2 Potentially Applicable Criteria/Requirements**

This subsection presents a discussion of the criteria and requirements that may apply to volatilized chemicals in the sewers. Two potentially applicable sets of air quality criteria, occupational standards and proposed RCRA Subpart S action levels, were identified and are presented for comparison to the modeled vapor emission concentrations. These criteria are used as action levels to evaluate risk and not as "cleanup standards". In addition to the air quality standards cited above, the City of Philadelphia Wastewater Control Regulations are potentially applicable to the sewer infiltration.

It should be noted that no applicable federal, State or local standards or criteria were identified for groundwater that is not a potential source of drinking water, such as that found beneath the Plant.

#### **6.1.2.1 Occupational Standards**

Air quality standards for occupational exposures are available for several chemicals for which chemical vapor emission modeling was performed. The occupational standards that may apply include Permissible Exposure Limits (PELs) that are established by OSHA, Threshold Limit Values (TLVs) that are developed by the American Conference of Governmental Industrial Hygienists (ACGIH), and Recommended Exposure Limits (RELs) that have been identified by the National Institute for Occupational Safety and Health (NIOSH). Of the occupational standards presented, only the OSHA values are regulatory.

The exposure limits that have been developed are protective of human health under occupational settings and assume that potential receptors are not using any form of respiratory protection. Long-term exposure limits are presented as Time-Weighted Average (TWA) values and consider cumulative exposure over an eight-hour work day. Short Term Exposure Limits (STELs) provide maximum exposure concentrations over a shorter time frame of 15 minutes. Another standard, defined by NIOSH and called the Immediately Dangerous to Life and Health (IDLH) concentration, is the chemical concentration in air that presents a potentially injurious and/or life threatening situation.

The potentially applicable occupational ambient air concentrations standards for modeled groundwater chemicals are presented in Table 6-3.

Based on the vapor emissions modeling performed for groundwater chemicals, none of the chemicals pose a significant occupational threat.



**TABLE 6-2**  
**VAPOR EMISSION MODEL RESULTS**  
**GROUNDWATER CHEMICALS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Chemical	Infiltrating Groundwater Concentration (mg/l)	Diluted Chemical Concentration (mg/l)	Chemical Vapor Concentration (mg/m <sup>3</sup> )
Acetone	900	1.09	$1.97 \times 10^{-6}$
Benzene	120	0.145	$3.37 \times 10^{-5}$
Cumene (Isopropylbenzene)	0.098	$1.18 \times 10^{-4}$	$7.31 \times 10^{-8}$
Ethylbenzene	0.010	$1.21 \times 10^{-5}$	$3.37 \times 10^{-9}$
Toluene	43	$5.20 \times 10^{-2}$	$1.46 \times 10^{-5}$
Xylenes	2.7	$3.27 \times 10^{-3}$	$5.97 \times 10^{-7}$
Phenol	490	$5.93 \times 10^{-1}$	$1.14 \times 10^{-8}$
2-Methylphenol	12	$1.45 \times 10^{-2}$	$2.40 \times 10^{-9}$
4-Methylphenol	32	$3.87 \times 10^{-2}$	$6.41 \times 10^{-10}$
2,4-Dimethylphenol	6.3	$7.62 \times 10^{-3}$	$5.47 \times 10^{-9}$
Anthracene	0.011	$1.33 \times 10^{-5}$	$4.83 \times 10^{-11}$
Fluorene	0.059	$7.14 \times 10^{-5}$	$1.93 \times 10^{-10}$
2-Methylnaphthalene	0.540	$6.53 \times 10^{-4}$	$1.38 \times 10^{-8}$
Naphthalene	4.4	$5.32 \times 10^{-3}$	$1.03 \times 10^{-7}$

**TABLE 6-3**  
**SUMMARY OF OCCUPATIONAL STANDARDS (mg/m<sup>3</sup>)**  
**GROUNDWATER CHEMICALS**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Chemical	OSHA PELs <sup>(1)</sup>		ACGIH TLVs <sup>(2)</sup>		NIOSH RELs <sup>(3)</sup>		
	TWA <sup>(4)</sup>	0STEL <sup>(5)</sup>	TWA	STEL	TWA	STEL	IDLH <sup>(6)</sup>
Acetone	1800	2400	1780	2380	590	NA	48,400
Benzene	3	15	32	NA	0.32	3.2	9,750
Cumene (Isopropylbenzene)	245	NA	246	NA	245	NA	40,000
Ethylbenzene	435	545	434	543	435	545	8,800
Toluene	375	560	147	NA	375	560	7,660
Xylenes	435	655	434	651	435	655	4,410
Anthracene	NA	NA	NA	NA	NA	NA	NA
2,4-Dimethylphenol	NA	NA	NA	NA	NA	NA	NA
Fluorene	NA	NA	NA	NA	NA	NA	NA
2-Methylnaphthalene	NA	NA	NA	NA	NA	NA	NA
2-Methylphenol	22	NA	22	NA	10	NA	NA
4-Methylphenol	22	NA	22	NA	10	NA	NA
Naphthalene	50	75	52	79	50	75	2,500
Phenol	19	NA	19	NA	19	60	950

- (1) Occupational Safety and Health Administration Permissible Exposure Limits, 29 CFR 1910.1000.  
(2) American Conference of Governmental Industrial Hygienists Threshold Limit Values, 1993.  
(3) National Institute for Occupational Safety and Health Recommended Exposure Limits, 1993.  
(4) Time-weighted average concentration.  
(5) Short-term exposure limit.  
(6) Immediately dangerous to life and health.  
NA Not available.

### **6.1.2.2 Proposed RCRA Subpart S Standards**

As a part of the proposed RCRA corrective action rule (55 Federal Register 30814), EPA proposed action levels that are health- and environmental-based levels determined by EPA to be indicators for protection of human health and the environment. The discovery of "contamination exceeding action levels would indicate a potential threat to human health or the environment which may require further study," whereas levels of contamination below the action level are "unlikely to require active remediation."

Only two of the groundwater chemicals identified in Table 6-2 have proposed RCRA Subpart S air quality action levels. These action levels are 7 mg/m<sup>3</sup> for toluene and 1 mg/m<sup>3</sup> for xylenes. The toluene and xylenes modeled concentrations presented in Table 6-2 are well below the corresponding proposed RCRA Subpart S action levels.

### **6.1.2.3 Wastewater Control Regulation**

In addition to the air quality standards cited above, the City of Philadelphia Wastewater Control Regulations are potentially applicable to the sewer infiltration. These regulations preclude discharge of any wastewater containing pollutants which may injure, adversely affect, or interfere with any wastewater treatment process; or constitute a hazard to humans or other biota, or may create an adverse effect in the receiving waters of the treatment plant; or violate any provision of the Federal Clean Air Act or local air quality regulations. In addition, the City of Philadelphia requires prior written approval to discharge benzene, cumene, ethylbenzene, xylenes, phenols, and toluene into its sewer system.

AlliedSignal's wastewater discharge permit only addresses groundwater recovered from recovery wells R-4, R-5, and R-6. It does not address sewer infiltration. AlliedSignal intends to discuss the potential applicability of the wastewater regulations to the apparent sewer system infiltration identified during the Phase II RFI. It should be noted that any waters recovered from remedial actions are not subject to the Organic Chemicals and Plastics and Synthetic Fibers Category Effluent Limitation Guidelines promulgated under 40 CFR Parts 414 and 416.

### **6.1.3 BASELINE RISK ASSESSMENT**

Risk assessment is the process where analytical results are evaluated qualitatively or quantitatively to assess the risks to receptors presented by exposure to chemicals in environmental media. The assessment is conducted using a four-step process: data evaluation, toxicity assessment, exposure assessment, and risk characterization. Each part of the risk assessment is discussed in detail in the following subsections.

#### **6.1.3.1 Data Evaluation**

Data evaluation includes a comprehensive review of available analytical and geological information upon which the baseline risk assessment is based. Site-specific chemicals of potential concern for each affected medium are identified, and a conceptual site model is developed consistent with the previously identified exposure pathways. Chemicals of Potential Concern (CPC) are screened from the chemicals detected at the Plant. All organic chemicals will be retained, subject to elimination based on availability of toxicological information and chemical toxicity.

CPCs are determined for each potentially impacted medium by evaluation of the analytical data and comparison to ambient concentrations. The focus is to determine if site media may present receptor risk above background levels. The presence of organic chemicals is assumed to be anthropogenic in origin for all media at the Plant. Potential contributions of organic chemicals to site media from other sources, although likely, is not considered.

Groundwater samples were collected from the shallow and deeper aquifers at the site. Several organic chemicals and metals were detected in the samples. All positively identified chemicals in groundwater were initially retained as potential chemicals of concern; however, nonvolatile metallic constituents and chemicals for which toxicity data are not available (acenaphthylene, dibenzofuran, and phenanthrene) were eliminated from further consideration. A summary of the groundwater potential chemicals of concern is provided in Table 6-4.

#### **6.1.3.2 Toxicity Assessment**

The toxicity assessment is the process of examination and compilation of available toxicological information for specific chemicals. Toxic effects imparted from chemical exposure include systemic toxicity and carcinogenicity. The potential for adverse health effects due to these two mechanisms is quantified by Reference Doses (RfDs) for systemic effects and Cancer Slope Factors (CSFs) for carcinogenicity. Both are described further in the following text.

An important component of the risk assessment process is the relationship between the intake of a chemical (amount of chemical absorbed by a receptor) and the potential for adverse health effects resulting from that intake. Dose-response relationships provide the means by which impacts can be quantified. The published information of doses and responses is used in conjunction with information on the nature and magnitude of human exposure to develop an estimate of potential health risks.

TABLE 6-4

**SUMMARY OF CHEMICALS OF POTENTIAL CONCERN  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

GROUNDWATER		
Acetone	Xylenes	Acenaphthylene
Benzene	Phenol	Anthracene
Cumene (Isopropylbenzene)	2-Methylphenol	Fluorene
Ethylbenzene	4-Methylphenol	2-Methylnaphthalene
Toluene	2,4-Dimethylphenol	Naphthalene
SURFACE WATER		
Benzene	Acenaphthene	Chromium
Toluene	Anthracene	Copper
Ethylbenzene	Fluorene	Iron
Phenol	Naphthalene	Lead
2-Methylphenol	Phenanthrene	Nickel
4-Methylphenol	Aluminum	Selenium
2,4-Dimethylphenol	Arsenic	Zinc

RfDs and CSFs have been developed by EPA for most of the organic chemicals of concern identified at the Plant. This section provides a brief description of these parameters. A summary of oral inhalation RfDs and CSFs for the potential chemicals of concern is provided in Table 6-5.

### **Reference Doses (RfDs)**

Systemic (noncarcinogenic) health effects imparted by a chemical are quantified through the use of a RfDs, developed by EPA. The RfD for a specific chemical is typically derived by dividing the No-Observed-(Adverse)-Effect-Level (NOEL or NOAEL) or a Lowest-Observed-Adverse-Effect-Level (LOAEL) by an appropriate uncertainty factor. NOAELs, etc. are determined from laboratory or epidemiological toxicity studies. The uncertainty factor is based upon availability of toxicity data.

The RfD incorporates the surety of the evidence for chronic health effects. Even if applicable human data exist, the RfD (as diminished by the uncertainty factor) still maintains a margin of safety so that chronic human health effects are not underestimated. Thus, the RfD is an acceptable guideline for evaluation of noncarcinogenic risk, although the associated uncertainties preclude its use for precise risk quantitation.

Table 6-5 summarizes RfD information for the potential chemicals of concern.

### **Cancer Slope Factors (CSFs)**

CSFs are applicable for estimating the lifetime probability (assuming a 70-year lifetime) of human receptors developing cancer as a result of exposure to known or suspected human carcinogens. This factor is generally reported by EPA in units of  $(\text{mg/kg/day})^{-1}$  and is derived through an assumed low-dosage linear relationship and an extrapolation from high to low dose responses determined from animal studies. The value used in reporting the CSF is the upper 95 percent confidence limit of the dose-response data. Table 6-5 summarizes CSF information for the identified potential chemicals of concern.

### **Weight of Evidence Classification**

The weight of evidence classification designates the likelihood that a chemical is a human carcinogen, based on both human and animal studies. The classification is as follows:

- A - Known human carcinogen.
- B - Potential human carcinogen. B1 indicates that limited human data are available. B2 indicates that there is sufficient evidence of carcinogenicity in animals but inadequate or no evidence of carcinogenicity in humans.

TABLE 6-5

**DOSE-RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

Chemical	Reference Dose (mg/kg/day)		Cancer Slope Factor (mg/kg/day) <sup>-1</sup>		USEPA Weight of Evidence
	Oral (Target Organ)	Inhalation (Target Organ)	Oral (Tumor Site)	Inhalation (Tumor Site)	
Acetone	1 x 10 <sup>-1</sup> <sup>(1)</sup> (liver, kidney)	-	-	-	D
Benzene	-	-	2.9 x 10 <sup>-2</sup> <sup>(1)</sup> (leukocytes)	2.9 x 10 <sup>-2</sup> <sup>(1)</sup> (leukocytes)	A
Cumene (Isopropylbenzene)	4 x 10 <sup>-2</sup> <sup>(1)</sup> (kidney)	3 x 10 <sup>-3</sup> <sup>(5)</sup> (CNS effects)	-	-	NA
Toluene	2 x 10 <sup>-1</sup> <sup>(1)</sup> (liver, kidney)	1.1 x 10 <sup>-1</sup> <sup>(1)</sup> (CNS effects)	-	-	D
Ethylbenzene	1 x 10 <sup>-1</sup> <sup>(1)</sup> (liver, kidney)	2.9 x 10 <sup>-1</sup> <sup>(1)</sup> (developmental toxicity)	-	-	D
Xylenes	2 x 10 <sup>0</sup> <sup>(1)</sup> (decr. body weight)	9 x 10 <sup>-2</sup> <sup>(6)</sup> (CNS effects)	-	-	D
Phenol	6 x 10 <sup>-1</sup> <sup>(1)</sup> (reduced fetal body weight)	-	-	-	D
2,4-Dimethylphenol	2 x 10 <sup>-2</sup> <sup>(1)</sup> (blood)	-	-	-	NA
2-Methylphenol	5 x 10 <sup>-2</sup> <sup>(1)</sup> (whole body)	-	-	-	C
4-Methylphenol	5 x 10 <sup>-3</sup> <sup>(5)</sup> (whole body)	*	-	-	C
Naphthalene	4 x 10 <sup>-2</sup> <sup>(3)</sup> (decr. body weight)	-	-	-	D
2-Methylnaphthalene	2 x 10 <sup>-2</sup> <sup>(4)</sup>	-	-	-	NA

**TABLE 6-5**  
**DOSE-RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
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Chemical	Reference Dose (mg/kg/day)		Cancer Slope Factor (mg/kg/day) <sup>-1</sup>		USEPA Weight of Evidence
	Oral (Target Organ)	Inhalation (Target Organ)	Oral (Tumor Site)	Inhalation (Tumor Site)	
Fluorene	4 x 10 <sup>-2</sup> <sup>(1)</sup> (blood)	-	-	-	D
Anthracene	3 x 10 <sup>-1</sup> <sup>(1)</sup>	-	-	-	D
Carbazole	-	-	2 x 10 <sup>-2</sup> <sup>(2)</sup> (liver)	-	NA
Fluoranthene	4 x 10 <sup>-2</sup> <sup>(1)</sup> (liver, kidney)	-	-	-	D
Pyrene	3 x 10 <sup>-2</sup> <sup>(1)</sup> (kidney)	-	-	-	D
Acenaphthylene	*	-	-	-	D

- (1) IRIS  
(2) Heast Table 3, 1993  
(3) Heast Table 1, 1992  
(4) Reference Dose calculated from oral LD<sub>50</sub>.  
(5) Heast Table 1, 1993  
(6) Heast Table A, 1991  
\* Currently Under Review  
- No Data Available



- C - Possible human carcinogen.
- D - Not classifiable as to human carcinogenicity.
- E - Evidence of noncarcinogenicity in humans.

Weight of evidence classifications for the chemicals of concern are provided in Table 6-5.

### **6.1.3.3 Exposure Assessment**

The exposure assessment combines receptor activity with chemical data to quantify the amount of chemical exposure that is possible for a given receptor. The dose estimates are receptor- and exposure-scenario-specific for all complete exposure pathways. Possible exposure pathways have been identified for all media at the Plant and have been discussed previously.

Two types of exposure are quantified for each complete exposure route. Noncarcinogenic exposure is that which occurs during the actual exposure period and is sometimes referred to as the "acute" dosage. Carcinogenic exposure is quantified over the entire lifetime of the receptor and is representative of the "chronic" or long-term exposure dose. The basis for the determination of the two different dose estimates is the biochemical mechanisms that results in either noncarcinogenic (systemic) adverse health effects or carcinogenicity.

The only complete groundwater chemical exposure pathway is the inhalation route for individuals that may come into contact with vapor emissions from manhole cover vents and the treatment plant sewer outfall. Although the exposure is likely to be inconsequential, all potential exposure will be evaluated to be certain of the risk potential.

The exposure to volatilized groundwater chemicals is conservatively evaluated at the vapor concentration, without the effects of atmospheric dilution or dispersion of vapors being considered. The receptors that are considered are children playing in the streets that may inhale vapors emanating from the manhole cover vents and adult employees at the sewage treatment facility outfall that may also inhale vapors.

Modeled groundwater chemical emissions are used for the calculation of exposure. The input values used for the determination of the groundwater inhalation exposure estimates are summarized in Table 6-6.

**TABLE 6-6**

**SUMMARY OF EXPOSURE ASSESSMENT INPUT PARAMETERS  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

Parameter	Value	Units	Rationale
Chemical concentration in air ( $C_{air}$ )	Modeled value	mg/m <sup>3</sup>	Based on analytical results
Air inhalation rate (InhR)	2.5 - adults and children	m <sup>3</sup> /hr	EPA, March 25, 1991
Exposure time (ET)	2 - adult 2 - child	hrs/day	Conservative estimate Conservative estimate
Exposure frequency (EF)	250 - adult 100 - child	days/yr	EPA, December, 1989 Conservative estimate
Exposure duration (ED)	30 - adult 6 - child	yr	EPA, March 25, 1991
Receptor body weight (BW)	70 - adult 15 - child	Kg	EPA, March 25, 1991
Receptor lifetime (LT)	70	yr	EPA, March 25, 1991

#### 6.1.3.4 Risk Characterization

This section of the risk assessment characterizes the risks associated with the identified receptor-exposure scenarios. Risks that are presented in this section are based on the methodology described in the Risk Assessment Guidance for Superfund (EPA, December 1989).

The potential for the incidence of adverse systemic (noncarcinogenic) health effects is quantified by the hazard quotient. The hazard quotient for a specific chemical and exposure route is determined by the following relationship:

$$HQ = \frac{Dose}{RfD}$$

Where: HQ = Chemical- and exposure-route-specific hazard quotient (unitless)  
Dose = Calculated noncarcinogenic exposure dose (mg/kg/day)  
RfD = Chemical- and exposure-route-specific reference dose (mg/kg/day)

The hazard index is the summation of all chemical- and exposure-route-specific hazard quotients for a given receptor. This value, when exceeding unity, indicates the potential for the occurrence of adverse health effects. However, the incidence of adverse health effects is not necessarily implied by a hazard index of greater than one. This is principally because the chemicals contributing greatest to the cumulative hazard index may target different organs in the human body.

For situations where hazard indices exceed a value of one, evaluation of chemical-specific target organs and the cumulative hazard quotients for each organ is required. Because of the uncertainty factors incorporated into the reference dose value, the exceedence of the hazard index (HI) value of one does not guarantee the occurrence of adverse health effects, but it is a indicator that the possibility exists.

Carcinogenic risks are calculated using the following equation:

$$ICR = Dose \times CSF$$

Where: ICR = Exposure route-specific incremental cancer risk  
Dose = Calculated chronic exposure dosage (mg/kg/day)  
CSF = Chemical- and exposure-route-specific cancer slope factor (mg/kg/day)<sup>-1</sup>

If the calculated value of the incremental cancer risk exceeds a value of 0.1, an exponential expression is used:

$$ICR = 1 - \exp(-Dose \times CSF)$$

The total risk that is experienced by a receptor under a given exposure scenario is equal the sum of the individual chemical risks. The incremental cancer risk is a quantitative measure of the cancer incidence in a population exposed under the evaluated exposure scenario.

Risks associated with the indirect exposure to groundwater chemicals discharged into the City combined sewer have been evaluated. As discussed previously, the inhalation pathway to two receptors (individuals at the treatment plant sewer outfall and at locations proximate to manhole vents) is complete, and dose estimates and associated risks have been determined. Table 6-7 summarizes the risks calculated for each exposure scenario.

For the recreational child exposed to vapors escaping from sewers, the HI for all chemical exposure is equal to  $1.7 \times 10^{-5}$ . Although not typically evaluated for children, the associated cancer risk increase is equal to  $7.7 \times 10^{-9}$ . The adult employee of the sewage treatment plant has an HI of  $9.2 \times 10^{-6}$  and an ICR of  $2.0 \times 10^{-8}$ . Volatilized ethylbenzene provides 71 percent of the noncarcinogenic risk, and benzene is the only contributor to the cancer risk.

#### **6.1.4 Conclusions**

Based on the results of the quantitative risk assessment, the following conclusions can be drawn.

Direct chemical contact with groundwater is not occurring because there are no identified users of groundwater within a one-mile radius of the Plant. However, under the evaluated scenario, human receptors are exposed to groundwater chemicals indirectly via inhalation of volatiles. The concentrations have been determined based on infiltration into sewers, subsequent dilution, and volatilization to the extent permitted by Henry's Law. The receptors that have been evaluated are recreational children playing in the streets and adult employees of the sewage treatment authority exposed at the sewer outfall.

Both scenarios have demonstrated negligible risks. The HIs for the child and adult receptors were determined to be  $1.7 \times 10^{-5}$  and  $9.2 \times 10^{-6}$ , respectively. Cancer risk increases for the child and adult are determined to be  $7.7 \times 10^{-9}$  (one cancer incidence in 130 million receptors) and  $2.0 \times 10^{-8}$  (one incidence of cancer in 50 million receptors), respectively. Therefore, no cleanup levels have been developed or identified as being applicable to the exposure scenarios.

**TABLE 6-7**

**RISK CHARACTERIZATION SUMMARY  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

Receptor/medium	Exposure Route	Hazard Index	Cumulative Hazard Index	Incremental Cancer Risk	Cumulative Cancer Risk
Recreational child/groundwater	Inhalation of volatile chemicals	$1.7 \times 10^{-5}$	$1.7 \times 10^{-5}$	$7.7 \times 10^{-9}$	$7.7 \times 10^{-9}$
Sewage treatment plant employee/groundwater	Inhalation of volatile chemicals	$9.2 \times 10^{-6}$	$9.2 \times 10^{-6}$	$2.0 \times 10^{-8}$	$2.0 \times 10^{-8}$

## **6.2 SURFACE WATER PATHWAY**

As previously discussed, groundwater discharge was noted at the inlet during the field investigation. The groundwater discharge flows directly into the inlet and may affect aquatic biota and downstream environments.

Human receptors are not considered to be at potential risk at the Plant because access restrictions make this exposure pathway incomplete. Although access to the inlet at the Plant is limited, some downstream locations along the inlet between the Plant and the Delaware River are potentially accessible by human receptors. The Rohm and Haas chemical production facility and the Arsenal Business Center are located along the inlet, and a boat launch is also located in close proximity to the confluence of the inlet and the Delaware River.

There are no identified water system intakes along the Delaware River in the vicinity of the Frankford Inlet; consequently, exposure routes associated with domestic water use are incomplete.

Chemicals contained in the groundwater discharges at the Frankford Plant are not expected to significantly impact the water quality of the inlet because of dilution with the bulk inlet water, but this scenario will be evaluated in the following subsections.

### **6.2.1 Potentially Applicable Surface Water Criteria/Requirements**

This subsection presents a discussion of the criteria and requirements that may apply to the surface water bodies at the Plant. Included in this discussion are the promulgated and other potentially pertinent values for surface water protection. It should be noted that the proposed RCRA Subpart S water quality action levels are based on human water consumption. Since downstream surface water is not presently being consumed by humans and it is unlikely that it will be in the future, comparison with the proposed Subpart S levels is inappropriate.

#### **6.2.1.1 Ambient Water Quality Criteria (AWQCs)**

AWQCs are nonenforceable federal regulatory guidelines and are of primary utility in assessing the potential for toxic effects in aquatic organisms. They may also be used to identify the potential for human health risks. Human health AWQCs consider both the acute and toxic effects from ingestion of both water (two liters per day) and aquatic organisms (6.5 g/day), and from ingestion of aquatic organisms alone.

AWQC values are presented for all organic chemicals detected in samples from shallow monitoring wells placed around the Frankford Inlet and for positively detected chemicals in the seep sample. A summary of applicable AWQC values for surface water is presented in Table 6-8.

#### **6.2.1.2 Pennsylvania Surface Water Quality Standards**

The commonwealth of Pennsylvania has established surface water classifications and quality standards that are outlined in the Pennsylvania Code, Title 25, Chapters 16 and 93. The guidelines presented in Chapter 16 have been developed for the protection of aquatic life and human health. Assignments of water use projections and exceptions to specific criteria are summarized in Chapter 93.

Chronic (continuous) and acute (maximum) criteria for protection of fish and aquatic life and human health criteria have been developed for many toxic substances. The criteria have been developed for aquatic organisms based on the results of bioassay studies or from evaluated standards developed by EPA. Human health standards have been determined as the threshold exposure concentration (for noncarcinogens) or as the exposure concentration that corresponds to a cancer incidence of one in one million ( $10^{-6}$ ) under prescribed exposure conditions.

The Delaware River and tidal portions of estuaries, including the Frankford Inlet, are protected for warm-water fishes and for migratory fishes in passage only. This is the lowest quality classification the commonwealth of Pennsylvania has. The water is not to be used for a livestock water supply or irrigation or for aesthetics and water-contact sports (swimming and related activities). Numerical standards for surface water constituents detected in samples from the shallow monitoring wells placed around the Frankford Inlet and the seep sample are presented in Table 6-8.

#### **6.2.1.3 New Jersey Surface Water Quality Standards**

Because the commonwealth of Pennsylvania and the state of New Jersey share primacy over the main stem of the Delaware River, consideration of the New Jersey water quality standards is appropriate. New Jersey surface water quality standards are outlined in the New Jersey Administrative Code, Title 7, Chapter 9, Subchapter 4. The standards establish classification, designate uses, and prescribe quality standards for all of the state surface water bodies.

TABLE 6-8

**SUMMARY OF SURFACE WATER QUALITY CRITERIA  
ALLIEDSIGNAL FRANKFORD PLANT  
PHILADELPHIA, PENNSYLVANIA**

Chemical	Pennsylvania Criteria <sup>(1)</sup>			Ambient Water Quality Criteria <sup>(2)</sup>			
	Fish and Aquatic Life Criteria (µg/L)		Human Health Criteria (µg/L)	Protection of Freshwater Aquatic Life (µg/L)		Protection of Human Health (µg/L)	
	Continuous (chronic)	Maximum (acute)		Acute	Chronic	Ingestion of Water and Fish	Ingestion of Water Only
2-Butanone	NA	NA	NA	NA	NA	NA	NA
Cumene (Isopropylbenzene)	NA	NA	NA	NA	NA	NA	NA
Benzene	128	640	1 <sup>(3)</sup>	5300 <sup>(8)</sup>	NA	1.2	71
Toluene	330	1650	14,300 <sup>(4)</sup>	17,500 <sup>(8)</sup>	NA	6800	200,000
Ethylbenzene	580	2900	1400 <sup>(4)</sup>	32,000 <sup>(8)</sup>	NA	3100	29,000
Styrene	NA	NA	NA	NA	NA	NA	NA
Xylenes	NA	NA	NA	NA	NA	NA	NA
Phenol	20 <sup>(5)</sup>	100 <sup>(5)</sup>	5 <sup>(5)</sup>	10,200 <sup>(8)</sup>	2560 <sup>(8)</sup>	21,000	4,600,000
2-Methylphenol	20 <sup>(5)</sup>	100 <sup>(5)</sup>	5 <sup>(5)</sup>	NA	NA	NA	NA
4-Methylphenol	20 <sup>(5)</sup>	100 <sup>(5)</sup>	5 <sup>(5)</sup>	NA	NA	NA	NA
2,4-Dimethylphenol	132	660	400 <sup>(4)</sup>	2120 <sup>(8)</sup>	NA	540	2300
Acenaphthene	17	85	20 <sup>(6)</sup>	1700 <sup>(8)</sup>	520 <sup>(8)</sup>	NA	20
Anthracene	NA	NA	0.003 <sup>(3)</sup>	NA	NA	9600	110,000
Dibenzofuran	NA	NA	NA	NA	NA	NA	NA
Fluorene	NA	NA	0.003 <sup>(3)</sup>	NA	NA	1300	14,000



**TABLE 6-8**  
**SUMMARY OF SURFACE WATER QUALITY CRITERIA**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
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Chemical	Pennsylvania Criteria <sup>(1)</sup>			Ambient Water Quality Criteria <sup>(2)</sup>			
	Fish and Aquatic Life Criteria (µg/L)		Human Health Criteria (µg/L)	Protection of Freshwater Aquatic Life (µg/L)		Protection of Human Health (µg/L)	
	Continuous (chronic)	Maximum (acute)		Acute	Chronic	Ingestion of Water and Fish	Ingestion of Water Only
2-Methylnaphthalene	NA	NA	NA	NA	NA	NA	NA
Naphthalene	43	135	10 <sup>(6)</sup>	2300 <sup>(8)</sup>	620 <sup>(8)</sup>	NA	NA
Phenanthrene	1	5	0.003 <sup>(3)</sup>	NA	NA	0.0028	0.031
Aluminum	NA	NA	NA	193,000 <sup>(8)</sup>	NA	NA	NA
Arsenic	190 <sup>(7)</sup>	360 <sup>(7)</sup>	50 <sup>(4)</sup>	As <sup>+3</sup> : 360	As <sup>+3</sup> : 190	0.018	0.14
Barium	NA	NA	NA	NA	NA	NA	NA
Calcium	NA	NA	NA	NA	NA	NA	NA
Chromium	221 <sup>(7)</sup> (total)	1716 <sup>(7)</sup> (total)	NA	Cr <sup>+3</sup> : 1700 Cr <sup>+6</sup> : 16	Cr <sup>+3</sup> : 210 Cr <sup>+6</sup> : 11	Cr <sup>+3</sup> : 33,000 Cr <sup>+6</sup> : 170	Cr <sup>+3</sup> : 670,000 Cr <sup>+6</sup> : 3400
Copper	12 <sup>(7)</sup>	18 <sup>(7)</sup>	1000 <sup>(6)</sup>	18	12	1300	NA
Iron	NA	NA	NA	NA	1000 <sup>(8)</sup>	NA	NA
Lead	3.2 <sup>(7)</sup>	82 <sup>(7)</sup>	NA	82 <sup>(7)</sup>	3.2 <sup>(7)</sup>	50	NA
Magnesium	NA	NA	NA	NA	NA	NA	NA
Manganese	NA	NA	NA	NA	NA	NA	NA
Nickel	160 <sup>(7)</sup>	1,400 <sup>(7)</sup>	632 <sup>(4)</sup>	1400 <sup>(7)</sup>	160 <sup>(7)</sup>	610	4600
Potassium	NA	NA	NA	NA	NA	NA	NA

**TABLE 6-8**  
**SUMMARY OF SURFACE WATER QUALITY CRITERIA**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**  
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Chemical	Pennsylvania Criteria <sup>(1)</sup>			Ambient Water Quality Criteria <sup>(2)</sup>			
	Fish and Aquatic Life Criteria (µg/L)		Human Health Criteria (µg/L)	Protection of Freshwater Aquatic Life (µg/L)		Protection of Human Health (µg/L)	
	Continuous (chronic)	Maximum (acute)		Acute	Chronic	Ingestion of Water and Fish	Ingestion of Water Only
Selenium	5	20	50 <sup>(4)</sup>	20	5	100	6800
Sodium	NA	NA	NA	NA	NA	NA	NA
Vanadium	NA	NA	NA	NA	NA	NA	NA
Zinc	110 <sup>(7)</sup>	120 <sup>(7)</sup>	5000 <sup>(6)</sup>	120 <sup>(7)</sup>	110 <sup>(7)</sup>	NA	NA

NA Criterion not available.

(1) Pennsylvania Code Title 25, Chapter 16.

(2) USEPA, Office of Water, 1991.

(3) Criterion corresponds to 10<sup>-6</sup> cancer risk level.

(4) Threshold effects level.

(5) Criterion value for total phenolics.

(6) Taste and/or odor threshold.

(7) Criteria based on an assumed total water hardness of 100 mg/L.

(8) Low observed effects level value. table 6-6

The Delaware River is designated as Zone 3 at the confluence of the Frankford Inlet. The designated uses for the Delaware River in this Zone are agricultural, industrial, and public water supply after reasonable treatment; wildlife; maintenance of resident fish and other aquatic biota; migration of anadromous fish; secondary contact recreation; and navigation. Additional physical and chemical standards apply; however, only the standard for total phenolics (0.005 mg/l, unless exceeded due to natural conditions) potentially applies to the seepage into Frankford Inlet from the Plant. No phenolic compounds were detected in the seep sample collected at the Plant; however, phenolics have been detected in samples collected from monitoring wells in close proximity to the Frankford Inlet.

### **6.2.2 Surface Water Risk Assessment**

As was true for the sewer infiltration pathway, all organic chemicals will be retained, subject to elimination based on availability of toxicological information and chemical toxicity. Similarly, all metal CPCs will be retained, subject to elimination.

All positively detected organic chemicals and metals in the seep sample and shallow monitoring wells in the vicinity of the Frankford Inlet (MW-104, MW-107, MW-109, MW-113, and MW-123) were initially retained for review as potential chemicals of concern. Since no surface water quality standards exist for 2-butanone, cumene, styrene, xylenes, dibenzofuran, 2-methylnaphthalene, barium, calcium, magnesium, manganese, potassium, sodium, and vanadium, these chemicals were eliminated from further consideration. The surface water CPCs that were evaluated for adverse environmental effects are summarized in Table 6-4.

Because of the absence of complete exposure pathways for human contact with surface water at the Plant, a quantitative evaluation of human risks posed by chemicals contained in surface water has not been completed. However, a conservative and qualitative determination of the potential risks to environmental and downstream human receptors can be made by comparison of chemical data to available criteria.

To assess the potential for environmental impacts by groundwater discharge to the inlet, maximum detected concentrations for chemicals in the shallow groundwater are adjusted in a manner similar to that employed for groundwater discharge to the sanitary sewer. Average tidal fluctuations of approximately six feet are noted for the inlet near the plant. At low tide, the inlet is without water, exposing about one foot of sediment material. The inlet is approximately 100 feet wide and 750 feet in length adjacent to the Plant. Therefore, during a 12-hour tidal cycle, approximately 380,000 cubic feet (2.8 million gallons) of water enter and leave the inlet by the Plant.

A rough estimate of the groundwater discharge to the inlet is a flow rate of 10,000 gallons per day or about 5000 gallons over a 12-hour tidal cycle. A dilution factor equal to  $1.8 \times 10^{-3}$  is obtained as the ratio of discharged groundwater to water exchanged in the inlet during the tidal cycle.

Table 6-9 presents a comparison of surface water quality standards to adjusted chemical concentrations for the chemicals detected in the seep sample and shallow monitoring wells in the vicinity of the inlet. Exceedences are noted for phenolics, PAHs and arsenic in the surface water. All other surface water/groundwater discharge chemicals are less than respective state or federal criteria.

### **6.2.3 Conclusions**

Based on the results of the qualitative risk assessment performed for the surface water at the Plant, the following conclusions can be drawn.

The discharge of groundwater chemicals to surface water at the Plant, specifically the Frankford Inlet, was qualitatively evaluated using comparison of diluted maximum chemical results to federal and state criteria for the protection of freshwater aquatic life and for the protection of human health. This qualitative comparison is considered to be conservative in view of the fact that most of the groundwater discharge is believed to be coming into the inlet from the south bank, an area of minimal chemical contamination.

All diluted chemical results were less than respective minimum water quality standards except those for arsenic, phenolics, and PAHs (PAHs - anthracene, fluorene, and phenanthrene). The phenolic criteria are based on Pennsylvania standards for organoleptic detection limits (i.e., they are not risk based). New Jersey standards for phenolics in surface water are numerically equivalent to the Pennsylvania standard. For arsenic and PAHs, the criteria that are exceeded are values that are protective of human health. The human health protection criteria assume the water and/or fish are being ingested, and they are based on a cancer risk increase of  $10^{-6}$ .

The effects that will be potentially felt by the downstream environment of the Frankford Inlet cannot be accurately assessed. However, the water quality of the Inlet and Delaware River in the vicinity of the Frankford Inlet is marginal. The area is characterized by urban and industrial development, and other potential contamination sources are noted to be present along the inlet. There are no present downstream consumers of surface water, and no commercial collection of aquatic foodstuffs is noted in the area. Thus, comparison of the diluted discharged groundwater with the exceeded criteria may not be appropriate.

**TABLE 6-9**  
**SURFACE WATER CRITERIA COMPARISON**  
**ALLIEDSIGNAL FRANKFORD PLANT**  
**PHILADELPHIA, PENNSYLVANIA**

Chemical	Maximum Detected Value (µg/l)	Diluted Concentration <sup>(7)</sup> (µg/l)	Surface Water Comparison Criterion (µg/l)	Criteria exceeded?
Benzene	53	0.9	1 <sup>(1)</sup>	No
Toluene	64	0.1	330 <sup>(2)</sup>	No
Ethylbenzene	53	0.09	580 <sup>(2)</sup>	No
Phenol	53,000	90	5 <sup>(1,3)</sup>	Yes
2-Methylphenol	22,000	40	5 <sup>(1,3)</sup>	Yes
4-Methylphenol	78,000	100	5 <sup>(1,3)</sup>	Yes
2,4-Dimethylphenol	87,000	200	5 <sup>(1)(3)</sup>	Yes
Acenaphthene	72	0.1	17 <sup>(2)</sup>	No
Anthracene	11	0.02	0.003 <sup>(1)</sup>	Yes
Fluorene	59	0.1	0.003 <sup>(1)</sup>	Yes
Naphthalene	19,000	30	43 <sup>(2)</sup>	No
Phenanthrene	49	0.09	0.003 <sup>(1)</sup>	Yes
Aluminum	206	0.4	193,000 <sup>(5)</sup>	No
Arsenic	90.0	0.2	0.018 <sup>(4)</sup>	Yes
Chromium	198	0.4	221 <sup>(2)</sup>	No
Copper	14.0	0.03	12 <sup>(2,6)</sup>	No
Iron	20,000	40	1000 <sup>(6)</sup>	No
Lead	52.1	0.09	3.2 <sup>(2,6)</sup>	No
Nickel	29.0	0.05	160 <sup>(2,6)</sup>	No
Selenium	17.7	0.03	5 <sup>(2,6)</sup>	No
Zinc	16.0	0.03	110 <sup>(2,6)</sup>	No

ND - Chemical not detected.

(1) Pennsylvania human health criterion.

(2) Pennsylvania aquatic life criterion (chronic/continuous).

(3) New Jersey surface water quality criterion for Delaware River Zone 3.

(4) USEPA AWQC for protection of human health, ingestion of water and fish.

(5) USEPA AWQC for protection of freshwater aquatic life, acute value.

(6) USEPA AWQC for protection of freshwater aquatic life, chronic value.

(7) Rounded to one significant digit.

### 6.3 UNCERTAINTIES AND LIMITATIONS

Uncertainty must be realistically associated with a risk assessment. Each individual element of the assessment has potential contributions that may be compounded throughout the process. However, sufficient safeguards have been implemented in each step to limit the potential bias for the final results.

The use of maximum detected concentrations or worst case exposure points allow for a conservative chemical evaluation for the quantitative risk determination. Modeling also presents the possibility for error; however, comparison of calculated results with measured quantities provided an assessment tool to identify gross inconsistencies.

The exposure assessment methodology uses assumptions that skew exposure estimates to the conservative side. For example, the assumption that all chemicals are 100% absorbed in the respiratory tract adds conservatism to the assessment of risk due to these exposure routes. The exposure assessment input parameters are also selected to be conservative for the receptors being examined.

Risk calculation is also viewed as conservative because the toxicological information that is used in the quantitative characterization are lowest- or no-observed-adverse-effects levels that are modified using the appropriate number of uncertainty factors and are reviewed intensively by the EPA.

The qualitative evaluation of the surface water at the Frankford Plant is considered to be acceptable because of the use of maximum concentrations, data from surrounding locations, site-specific input values, and the lowest criteria available for comparison. e-specific input values, and the lowest criteria available for comparison.

## **7.0 CONCLUSIONS AND RECOMMENDATIONS**

### **7.1 CONCLUSIONS**

The following conclusions can be made for the Phase II RFI.

1. The extent of shallow groundwater contamination has essentially been defined. Only limited offsite contamination was found, immediately west of the Plant. Contaminated shallow groundwater migration appears to be limited by groundwater withdrawal from the six Plant recovery wells as well as infiltration into the Plant sanitary sewer system and the City combined sewer system and seepage into the Frankford Inlet.
2. The extent of deep sand unit groundwater contamination was not completely determined. However, this is not believed to be important, as there do not appear to be significant exposure pathways for deep sand unit groundwater. The majority of the deeper groundwater beneath the Plant appears to flow towards groundwater discharge point(s) along the south bank of the Frankford Inlet.
3. The silt-clay semi-confining unit only occurs on the Plant roughly between Main Street and the Frankford Inlet/former Frankford Creek channel. Thus, this is the only portion of the Plant having both a shallow aquifer and a deep sand unit aquifer.
4. Tides appear to have a limited effect on the shallow and deeper aquifers at the Plant. No meaningful changes in groundwater flow direction due to tidal influences were noted.
5. Relatively minor amounts of groundwater appear to be seeping into Frankford Inlet. Groundwater seeping into the Frankford Inlet would be diluted by the inlet waters. The dilution model used predicted that two Pennsylvania surface water standards (phenolics and PAHs) and two human health federal AWQC (PAHs and arsenic) would be exceeded. The phenolic criteria are based on organoleptic detection limits, and are not risk-based. The PAH and arsenic criteria are based on human consumption of surface water and ingestion of fish. There are no known drinking water intakes downstream of the Plant, and no commercial collection of aquatic food stuffs is noted in the area. Thus, comparison with these criteria may not be appropriate.

6. No evidence of significant contaminated groundwater infiltration into Plant storm sewers was identified. However, infiltration into City combined sewers and Plant sanitary sewers appears to be occurring.
7. No groundwater users within one mile of the Plant were identified during the well survey. Thus, the only viable groundwater exposure pathway is volatilization of groundwater chemicals that have infiltrated into the city sewer lines. A risk assessment of this pathway determined that it was not significant. Groundwater organic chemicals infiltrating into the sewer lines will likely be biodegraded in the Northeast Water Pollution Control Plant. However, this will be evaluated further.
8. Plant drinking water lines have been outfitted with backflow preventers. Recent analytical data indicate the water is safe to drink.
9. Explosive atmospheres do not appear to be forming in the Plant and downstream city sewer lines. The highest LEL level recorded during the period between July and December 1993 was only 32 percent of the LEL. This measurement was taken in the city interceptor south of the Plant.

As discussed in the Phase I RFI, contaminated soils are found beneath the Plant surface. However, direct exposure to these soils is precluded by the gravel and asphalt capping covering the Plant surface. Exposure to these soils during excavation is possible. Plant workers have been trained and provided personal protective equipment to comply with occupational safety regulations, and are therefore not considered susceptible to soil exposures. Corrective measures for soil inside the Plant are not believed to be necessary based on this exposure scenario.

No corrective measures for shallow groundwater viewed from the perspective of human health are believed to be required, based on the lack of use of groundwater as a drinking water source. Whether corrective measures are required for shallow groundwater because of infiltration into combined city sewer lines remains to be determined. This issue depends on the impact of the chemicals infiltrating the sewers on the Northeast Water Pollution Control Plant.

An evaluation of need for corrective measures for deeper groundwater and groundwater seepage into the Frankford Inlet cannot be made at this time based solely on the data generated in the Phase II RFI. Evaluations of the data presented in the Phase II RFI report indicates the risk from the seepage may be minimal and that the use of deeper groundwater as a drinking water source is unlikely. Additional information is required to confirm these assertions.



## **7.2 RECOMMENDATIONS**

The following recommendations for future work are made.

1. It is believed that the City sewer system infiltration apparently identified during the Phase II RFI should neither interfere with the City wastewater process nor adversely affect the treatment plant receiving waters. However, AlliedSignal has not discussed the apparent infiltration with City of Philadelphia personnel. It is recommended that these discussions be held.
2. Since no Frankford Inlet surface water quality data are available, a conservative surface water bulk dilution model was used to predict the effects of groundwater seepage into the inlet. The model predictions should be field verified by collecting a limited number of surface water samples from the inlet.
3. Available data indicate that deeper groundwater is infiltrating into City sewers near the Plant and/or seeping into the Frankford Inlet. However, existing data are insufficient to conclusively confirm this judgment. Therefore, installation and monitoring of additional deeper groundwater piezometers is recommended, to confirm the discharge points.
4. The hydrogeological system at the Plant is complex. Groundwater elevations and flow patterns may vary significantly in response to the amount and frequency of precipitation and seasonal variations. Therefore, a long-term groundwater level monitoring program is recommended to provide additional hydrogeological data on these possible variations.

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